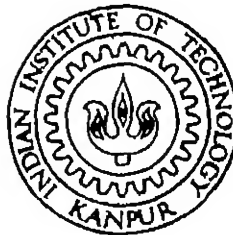


SIMULATION MODEL FOR DYNAMIC SCHEDULING OF BUSES ON A CORRIDOR-A CASE STUDY FOR DELHI RING ROAD

by
SHANTI KUMAR V.V.



DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

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*A Thesis submitted for the partial
fulfilment of the Requirements
for the Degree of
Master of Technology
by*

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INDIAN INSTITUTE OF TECHNOLOGY**

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DEDICATED

to

MY BELOVED PARENTS

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ABSTRACT

A model is developed to simulate the public transit system on a corridor with Object Oriented Approach. This model has the capability for dynamic scheduling of vehicles on a major corridor of a metropolitan city. This model simulates the public transit system on any route network, and suggests the optimal utilization of vehicles which minimizes the passenger waiting times at all stops. This model has a flexibility with respect to arrival of passengers to a stop. A stop may have any one of Exponential, Normal, or Gamma probability distributions of passenger arrival, and different parameters of distribution. This model displays the location of buses on the corridor of a city network at every five minute interval using concurrent mode of animation. This model supports the interactive graphics which enables the user to obtain the information of stops and buses, or to quit the simulation process at any instant of time. This model is tested with a case study of Dlehi ring road, on which the public transit system is simulated. A tentative timetable covering the morning peak period is prepared with 24 buses and is fed to the model. The model has suggested 19 additional buses, and revised the timetable.

CHAPTER I

INTRODUCTION

1.1 PROLOGUE

Public transport has become an integral and essential feature of cities in both developed and developing countries. In populous and developing countries like India, where urbanization trend is on the increase, mass transit system like commuter rails and bus transportation are mostly unavoidable. In most of the Indian cities, public transportation is inadequate and congestion is severe. Despite massive infusion of investment, the transportation crisis in metropolitan areas has been growing. Traffic congestion, air pollution, urban sprawl, and the need for energy conservation provide convincing evidence that drastic actions must be taken to improve the mass transit system in India in order to alleviate these problems.

In India, among various means of public transportation, the bus transport is most important and dominating because of its door-to-door accessibility and flexibility in operation. The success of public bus transport however depends on the efficient operational management looking to the need of the passengers. The demand for bus transportation is very high, trip length is short, and it is a cheaper mode because of the subsidy provided by the government in different ways. Bus transportation system in metropolitan cities involves the movement of large number of people between relatively small number of given locations. Bus transportation system should provide adequate mobility to various locations to satisfy the demand at all the locations.

In a metropolitan area the bus routes are basically designed in two different ways: *direction oriented* - where the bus moves along major corridors in certain directions; *destination oriented* - where the routes are designed to satisfy the demand from one node to the other. In direction oriented, the idea is that the persons board the bus at different nodes on major corridors, and move with high speeds in specific directions. These routes generally have heavy demand and high frequency of operation. The destination oriented routes are designed to satisfy the demand among major O-D pairs and provide accessibility to various nodes. The demand at these major nodes will be generally high, however the demand at various intermediate nodes may not be high. Among various issues of direct concern such as route design, bus allocation, bus scheduling, crew scheduling, and maintenance scheduling, the design of bus routes and bus scheduling may be considered as of prime importance.

In the present planning methods, after the route path is designed, the scheduling plans are prepared based on level of service, normally defined in terms of load factor. As the daily demand matrix for the public transport is available, the number of bus trips on a particular route are determined for the whole day. The number of buses that operate on particular route in both directions is decided subject to the operational constraints. In this way the timetable is prepared for the day where we have minimum headway during morning and evening peak periods, and on other times the headway is generally twice the peak headway.

1.2 PROBLEM STATEMENT

Economy in operation, reliable, and adequate level of service to the users should be the primary objectives of any bus transport management. It is imperative that the desired level of services to the passengers should be met by the minimum amount of resources. In order to achieve the above objectives it is necessary to investigate the following

- Structuring of the routes in order to meet the demand in an efficient manner on existing transit network.
- Determination of the minimum fleet size for a specified level of service for the system.
- Determination of the schedules with the minimum fleet size determined above to minimize the overall system cost.

For the routes along the major corridors, the specific problems which come up are -

- The significant variation of passenger demand from hour to hour
- The desired frequency during the peak period is quite high
- The arrival of passengers at the bus stops follows different probability distributions which is complex to model

For such routes - the load factor becomes very heavy during certain periods, passenger waiting time at stops also increases considerably causing discomfort, inconvenience, etc. The demand on these routes is also significantly affected by some other factors such as closing of cinemas, schools, factories, offices, etc.

In our present bus system operation, a fixed number of buses are operated as per a pre-determined time table and no consideration is given to the contingencies or bus breakdowns. In transportation and traffic engineering lot of electronic instrumentation is deployed, but a very little information is reported to improve the public bus transportation system.

To improve the system of operation, it is desirable to have dynamic scheduling based on actual demand pattern.

1.3 OBJECTIVES OF THE STUDY

The main objectives of the study includes the following tasks related to the scheduling of public bus transportation system on a route network of a city.

1. Generation of passengers at different stops as per different probability distributions.

- 2 Simulation of the movement of buses from one stop to the other, and scanning of passengers in the bus and at the stop
- 3 Estimation of statistics for passengers with respect to waiting time
- 4 Collection of information about the queues at different stops and decide the optimum scheduling of additional buses that may be available
- 5 Graphic display of movement of buses on route network at a fixed interval of time, and information of stops and buses

1.4 LITERATURE REVIEW

Anderson et al , (1979) have described a flexible simulation model of an urban bus route in peak hour traffic. The simulation program has been presented with particular emphasis on the facility for interactive control of the simulation run and for presentation of overall and detailed statistics from the simulation. An independent statistical program system based on the mathematical models underlying the simulation model has been used to provide input parameters for the simulation. The prime application of their simulation model is to run the program together with an on-line system that collects data from the real bus traffic and presents its status on a display. If a difficult situation occurs, the simulation program can be consulted for testing different ways to tackle the problem. They have built the model to handle one bus route that may consists of several service variants.

Friedman(1976) formulated a mathematical model of a general public transportation network, and suggested an optimized procedure to schedule the buses' departure times. The author has assumed that the network

operates under known deterministic conditions the lines' routes, the stations' locations, the number of passengers and the traffic intensity are given. For the sake of lucidity the model, the model first developed under the assumption that the loading as well as unloading times of passengers are zero. Afterwards the consequences of the relaxation of this supposition are investigated. The performance index of the system is the average waiting time of passengers, and it has to be minimized by a proper choice of decision variables - i.e. the buses' departure times - without violating the constraints of prescribed number of buses, and drivers.

Friedman (1975) suggested a rapid solution to the apparently simple problem of finding the minimum number of buses that are required to keep up a two way lane with prescribed departure and travel times with the following assumptions

- The buses traverse only the given lane.
- A bus that arrives first at a terminal will be the first to leave it.

No empty runs buses from one stop to the other. This procedure for finding the minimum number of buses that are needed to maintain a two way lane was utilized as part of a dynamic programming algorithm which means to establish the optimal values of the departure times of buses without violating the constraint of having a given number of them.

Dhingra (1983) has developed a simulation model for the scheduling problem of public bus transportation system, which simulates the flow of passengers on all the nodes of the network and the movement of vehicles on all the routes of the network, thereby taking into account the interaction effects of

overlapping, crossing, merging, and diverging routes. Routes have been designed based on travel demand, and assumed to be independent of schedules. The use of a vehicle over multiple routes has not been covered.

Ceder (1986) provided alternative methods for constructing bus timetables using passenger load data, and attempted to fulfill six major objectives: to evaluate alternative timetables in terms of required resources, to improve the correspondence of bus departure times with passenger demand, to provide alternative timetables for the schedulers' use in specific scheduling situations, to permit direct bus frequency changes for possible exceptions (known to the schedulers) which do not rely on passenger demand data, to allow the construction of the timetables with headway smoothing techniques; and to integrate different headway setting, and different timetable construction methods.

Dumas et al., (1990) presented an algorithm that solves the problem of finding the vehicle schedule which minimizes total inconveniences for travel along a fixed path, where service times at nodes are constrained by time windows, and where inconvenience is modeled using convex functions of the service times. It has been shown that the complexity of the algorithm, expressed as a number of unidimensional minimizations, is on the order of the number of nodes for convex inconvenience functions. An extension was proposed which includes linear costs on waiting times, and discrete service time variables.

Scheele (1980) formulated a problem to determine the complete travel pattern and to decide which bus frequencies to use on the various lines. The problem is formulated as a non-linear programming problem in the form of a compound minimization problem. The assumptions made to simplify this

problem are - the network of streets on which certain bus lines have been set up is given, the total number of buses is given, the total demand for bus transportation is given in the form of the marginal totals of an origin-destination matrix. An iterative algorithm to solve this problem is developed.

CHAPTER II

SIMULATION MODEL

2.1 *USE OF DIGITAL SIMULATION*

The mass transportation network of a major urban area necessarily involve a large number of logical sequence of decisions in the flow logic. The scheduling process being intricate requires the use of digital simulation. Digital simulation may be defined as, 'a numerical technique for conducting experiments on a digital computer with certain types of mathematical and logical models that describe the behavior of the complex system (or some part thereof) over extended periods of real time' (Naylor et al, 1967) Simulation serves different functions in system analysis and design. Digital simulation has the following additional advantages -

- I Data can be generated which enables the researcher to study and experiment with complex internal interactions of a given system and thus better understanding of the nature of interactions.

- 2 Simulation of complex systems yield valuable information for identifying the dominant parameters governing the system operation
- 3 It is useful in validating the component models in conjunction with the global modeling of a system

2.2 OBJECT ORIENTED PROGRAMMING (OOP) APPROACH,

This model is developed with OOP approach in C⁺⁺ on Turbo C⁺⁺ platform. This section gives a brief *idea* of OOP approach, and the use of this approach in this model. This section helps in understanding the OOP approach, and thus the program very easily, however, the readers having the sufficient knowledge of OOP approach may skip this section with out any difficulties.

OOP is a way of organizing programs. The emphasis is on the way programs are designed, not on the details of individual operators. In particular, OOPs are organized around objects which contain both data, and functions that act on that data. A class is a template for a number of objects. The fundamental *idea* behind OOP approach is to combine both data, and the functions that operate on that data into a single unit, which is called an object. An object's functions called member functions in C⁺⁺, provide the only way to access its data. If for example, you want to read a data item in an object, you call a member function in the object. It will read the item, and return the value to you. The data is hidden, so it is safe from accidental alterations. Data, and its functions are said to be encapsulated into a single entity. If you want to modify the data in an object, you know exactly what

functions interact with it the member functions in the object. No other function can access the data. This simplifies writing, debugging, and maintaining the program.

A C⁺⁺ program typically consists of a number of objects which communicate with each other by calling one others member functions. Thinking in terms of objects, rather than functions has a surprisingly helpful effect on how easily programs can be designed. This results from the close match between objects in the programming sense, and objects in the real world (Lafore, 1994)

2.3 MODEL DESCRIPTION

In the previous section the concept of OOP is briefly introduced. This section, now describes the model, and discuss how the concept of OOP is used to develop this model.

This model covers the simulation of public *Bus* transportation system on a route network of a city given travel demand using heuristic approach. The stochastic nature of flow of passengers and vehicles in a network necessitates the use of simulation modeling to achieve the objectives mentioned in section 1.3. The simulation model developed in this study simulates at micro level the arrival of passengers at all *Stops* as per different probability distributions, and the movement of *Buses* from one *Stop* to the other. The salient features of the model that accounts various complexities of the system are as follows -

- 1 The model simulates simultaneously the flow of passengers at all the *Stops* of the network, and the movement of flow of vehicles between all *Stops* of the network
- 2 The model takes into account the stochastic nature of passenger arrivals. For each node, a probability distribution and its parameters are to be specified reflecting the arrival gap characteristics. Exponential, Normal, and Gamma distributions have been associated with each *Stop* for the complete simulation run
- 3 This model suggests the schedule of an extra *Bus* from any of the terminals which may have extra *Buses*, based on some heuristic approaches. Also the user can accept or reject the suggestion made by this simulation model
- 4 This model, for every five minute interval displays graphically the locations of *Buses* on the network, and the information of *Stops* and *Buses* using concurrent mode of animation
- 5 The graphic display is highly user interactive, that the user can *Stop* the simulation run at any instant of time, and quit the graphic display

The program developed for this model is divided into a number of objects. Each *Bus Stop* on the network is considered as one object of class *Stop*. Similarly, each *Bus* is also treated as one object of class *Bus*. This program can handle a system with any number of *Stops* and *Buses*. If, for example, there are M number of *Stops*, and N number of *Buses*, this program dynamically creates memory for M *Stop* objects, and N *Bus* objects. The data structures associated with *Stop* objects, *Bus* objects are Linked Lists, and Queues, to maintain the passengers in each *Stop*, and each *Bus*, and to maintain the queue of departing

Buses at each *Stop*. The detailed description of *Stop* objects, and *Bus* objects will be given in later sections

2.4 MODEL INPUT AND OUTPUT

This model takes input from four different files -

- 1 In first input file will have the information of all *Stops* on the route network. The first element in input file, '*STOP_XY.IN*' will be *MAX_STOP*, the maximum number of *Stops* under consideration on the network of a city. The information of each *Stops* with respect to its sequence number, x and y coordinates, the desired probability distribution of passengers arriving at that *Stop* (*EX* for Exponential, *NR* for Normal, and *GM* for Gamma) and its parameters, and the total number of *Buses* available at that *Stop* have to be stored in this file.
- 2 In the second input file the information of all *Buses* will be stored. The first element in the input file '*BUS_INFO.IN*' will be *BUS_CAP*, the maximum capacity of *Bus*. The information of the each *Bus* (that are presently being operated in the system) with respect to its sequence number, starting terminal, starting time, and direction of movement on the network (*CW* for clock wise, and *ACW* for anti clock wise) will have to be stored in this file.
3. The input file No 3, '*TIME_TAB.IN*' will have the departure times on all *Buses* at each of the *Stop* on the network of the city. The *Bus id* number, and its departure time, following the *id* number of *Stop* will be the right format. In this

way the departure times of all *Buses* at each *Stop* will have to be stored in this file

- 4 The input file No 4, '*LINKTIME IN*' consists of travel times on all the links of the network. The link in terms of starting *Stop*, and ending *Stop* has to be mentioned in the input file, then follows the travel time on that link, and the direction of that link, either CW or ACW.
- 5 The input file No 5, '*OD_MATRIX*' will hold the OD matrix of size *MAX_STOP* in which each element represents daily demand of passengers from one *Stop* to the other.

The output of this simulation model is in the form of graphic display mostly, and can be classified into three categories -

- 1 At every five minute interval the graphic display of the network of the city, and the locations of *Buses* on the network.
- 2 At every five minute interval the graphic display of *Stop* information with respect to the sequence *id* number of the *Stop*, the number of passengers waiting at that *Stop*, the average waiting time of those passengers who board the last departed *Bus* from that *Stop*, the departure time and sequence number of the next *Bus* from that *Stop*, and the number of spare *Buses* that are available at that *Stop*.
- 3 At every five minute interval the graphic display of *Bus* information with respect to the sequence *id* number of the *Bus*, the no of passengers occupied the *Bus*, the departure time and sequence number of previous *Stop*, and next *Stop*.
- 4 Graphic display of suggestion of additional *Bus* that can be scheduled from any of the terminals if satisfies all the conditions.

- 5 The final output file gives the schedule of all *Buses* including the newly scheduled additional *Buses*, from all *Stops*

2.5 MODEL FORMULATION

This section explains in detail the formulation of the model, and its development. As explained in section 2.2, depending on the size of the problem, this model creates the *Stop* objects, and *Bus* objects. This section is divided into seven parts for the better understanding.

In part one the general flow diagram is illustrated which gives the idea of how the different modules or functions of the model are inter-related. In parts two and three of this section the data and member functions associated with each *Stop* object, and *Bus* object are explained. In part four the beginning of simulation process is described. In part five it is explained how the passengers will be generated at each *Stop* in the model. In part six the techniques of scanning the *Stops*, and *Buses* is discussed. In part seven the strategy to find the best *Stop* from which an additional *Bus* could be scheduled is described. In part eight the method used in this model to compute the location of *Buses* on the route network is explained. The last part i.e. part nine of this section discusses the termination criterion of the model.

2.5.1 GENERAL FLOW DIAGRAM OF MODEL

The rough flow diagram shown below gives a precise idea how the model works, or how the various functions are inter-related to each other. However each function and its sub-functions will be explained in later sections with the help of flow charts.

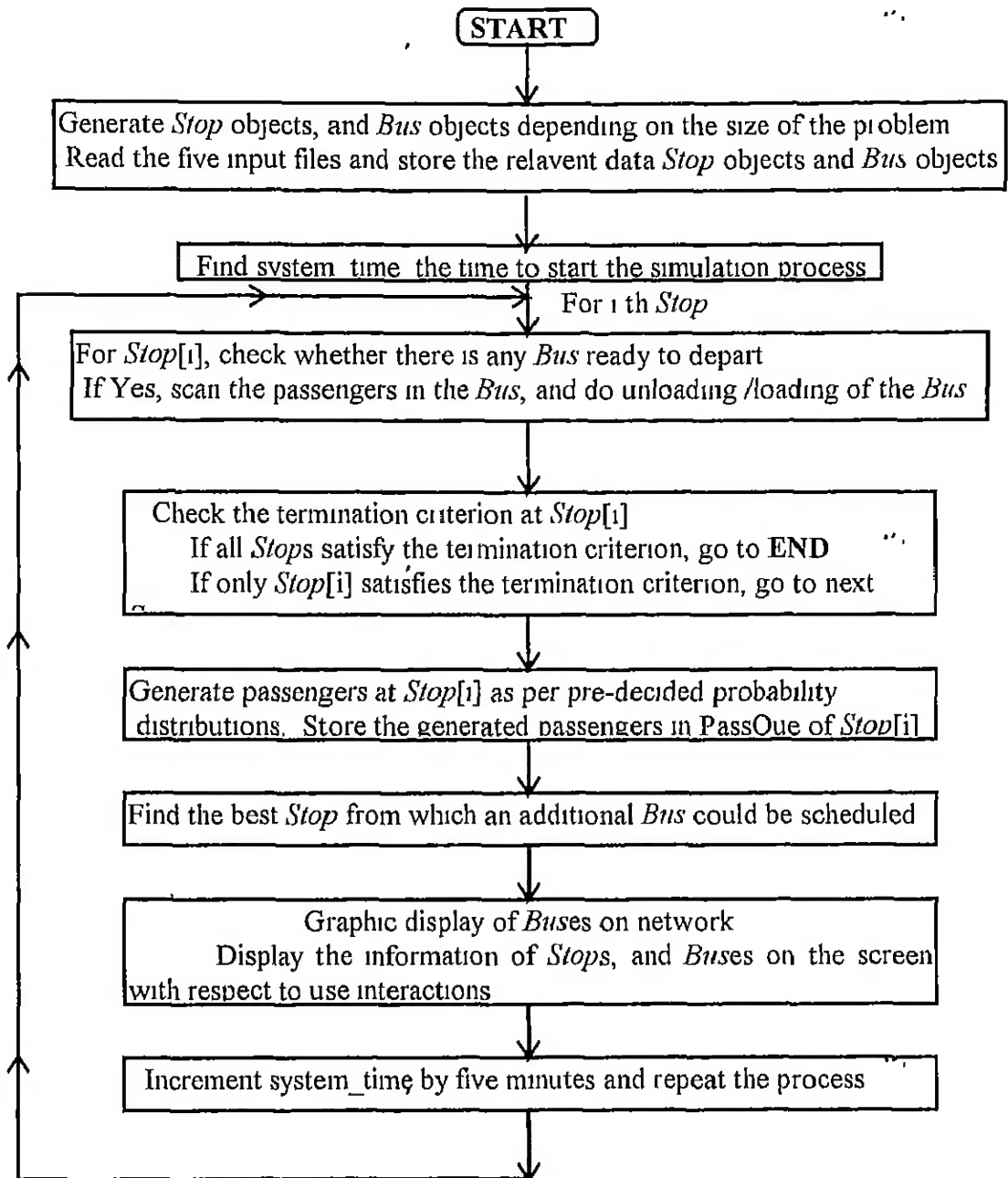


Fig. 2.1 General Flow Diagram of the Model

2.5.2 STOP OBJECTS

There will be *MAX_STOP* number of *Stop* objects created by the program. Each *Stop* object will have the following data items, and member functions to access the data from outside functions, and to interact with its data.

a) DATA ITEMS :

- *id* Sequence number of the *Stop*
- *x_co, y_co* X, and Y coordinates of *Stop*
- *dist* Desired probability distribution of passenger arrivals at *Stop*
Can be any one of *Exponential*, *Normal*, or *Gamma*
- *par1* First parameter of the desired probability distribution
- *par2* , Second parameter of the desired probability distribution
- *tot_bus* . Total number of *Buses* a *Stop* has
It is equal to zero if a *Stop* is not a terminal
- *free_bus* . Spare or additional *Buses* that are available from a *Stop*
- *tot_wait* . Total waiting time of all passengers served at the *Stop*
- *avg_wait* . Average waiting time of those passengers who board the
last *Bus* departed from *Stop* at any instant of time
- *PassQue* The queue of passengers arrived at the *Stop* as per
particular distribution. Each element of *PassQue* will consist of the arrival
time of a passenger, and his/her destination. Whenever a passenger is
generated, he/she will be stored in the *PassQue* of respective *Stop*, and
similarly when a *Bus* departs the *Stop* he/she will be deleted from the
PassQue, and stored in *PassLink* of that *Bus*.

- *BusQue* The queue of departing *Buses* from the *Stop*. In the increasing order of their departure times. Each element in *BusQue* represents the *Bus id* number, its departure time, and its direction of movement. In other way, this is the time table for the *Stop*. Whenever a *Bus* departs the *Stop*, the first *Bus* in the *BusQue* will be deleted, so that the next *Bus* will be ready to depart.

b) **MEMBER FUNCTIONS :**

- *get_data(stop_no, x_co, y_co, distr, par1, par2, tot_bus)*
This function stores the data, obtained from the input file No 1 into the respective *Stop* object.
- *get_timetab(bus_no, bus_time, dirn)*
This function stores the details of departing *Bus* i.e. the *Bus* number, its departure time, and its direction of movement in the *BusQue* of object *Stop*.
- *return_id()*
This function returns the *id* number of a *Stop*, and is useful to check the *id* number of a desired *Stop*.
- *return_first_bus()*
This function returns the *id* number of *Bus* which is next to depart from the *Stop*.
- *return_first_time()*
This function returns the departure time of *Bus* which is next to depart from the *Stop*.
- *return_last_time()*

This function returns the departure time of last *Bus* from the *Stop*. This function is useful to check whether the *Stop* is empty or not.

- *move_first_bus()* .

This function deletes the first *Bus* from *BusQue* when it departs the *Stop*, i.e. when ever a *Bus* departs a *Stop*, *BusQue* of that *Stop* will be updated.

- *add_pass()* .

This function stores the randomly generated passenger to the *PassQue* of the *Stop*.

- *del_pass()*

This function deletes the passenger from the *PassQue* of the *Stop* when the passenger boards a departing *Bus*.

- *population()* .

This function returns the *population* of passengers, i.e. the number of passengers in the *PassQue* of the *Stop*.

- *return_tot_wait()*

this function returns the *tot_wait* of the *Stop*.

- *return_avg_wtime()*.

This function returns the *avg_wait* of those passengers who board the previous departing *Bus* from the *Stop*.

- *give_free_bus()*

This function returns *free_bus*, the number of spare buses that the *Stop* has.

- *decrement_free_bus()* .

This function decrements the *free_bus* of the *Stop*, when an additional *Bus* has been scheduled from the *Stop*.

- *return_x_co()*

This function returns the *x_co* of the *Stop*

- *return_y_co()*

This function returns the *y_co* of the *Stop*

- *return_no_bus()*

This function returns the number of *Buses* that are yet to pass through the *Stop*

This function, when called checks the *BusQue* of a *Stop* and returns the number of *Buses* in *BusQue*. If there are no *Buses*, i.e. if the last *Bus* has departed, this function returns zero which implies the *Stop* is empty

- *return_par1()*

This function returns the first parameter of the probability distribution at the *Stop*

- *return_par2()*

this function returns the second parameter of the probability distribution at the *Stop*

- *check_distr(d) :*

This function compares the distribution *d* given to this function as argument with the desired distribution at the *Stop*, and returns YES if both are same, and returns NO if not

2.5.3 **BUS OBJECTS**

MAX_BUS, the number of *Bus* objects to be created by the program, depends on the *tot_bus* of each *Stop*. The *MAX_BUS* is nothing but the sum of *tot_bus* of all *Stops*. But *FLEET_SIZE*, the number of *Buses* being operated

on the route network, is initially equal to the number of *Bus* objects given in the input file No 2 *FLEET_SIZE* will be incremented by one unit when an additional *Bus* is scheduled. The value of *FLEET_SIZE* can not exceed *MAX_BUS*, as no additional *Bus* can be scheduled if there are no *free_bus* at each *Stop*. Now let us look into the data items, and member functions of each *Bus* object

a) **DATA ITEMS :**

- *id* Sequence number of a *Bus*
- *term_id* Sequence number of starting terminal of the *Bus*
- *dirn* Direction of the *Bus* movement on the route network
 CW - Clock Wise or *ACW* - Anti Clock Wise
- *prev_stop* Sequence number of previous *Stop*
- *prev_time* Departure time at previous *Stop*
- *PassList*: The Linked List of passengers who had occupied the *Bus*
 Each element of *PassList* comprises the destination of a passenger. When ever the *Bus* reaches a *Stop*, the *PassList* in the *Bus* will be scanned, and all those passengers whose destination is that *Stop* will be deleted from the *PassList*, and the passengers from *StopQue* will be added to the *PassList* of the *Bus* subjected to the capacity constraint of the *Bus*.
- *StopQue*: The queue of *Stops* to which the *Bus* has to travel. Each element of *StopQue* comprises the *id* number of a *Stop*, and the departure time of a *Bus* at that *Stop*, in the increasing order of time. In other way this is the time table for the *Bus*. When ever a *Bus* reaches a *Stop*, the first element will be removed from the *StopQue*.

b) **MEMBER FUNCTIONS :**

- *get_data(id, term_id, dirn)*

This function gets the data, the sequence number of a *Bus*, its starting terminal, and its direction of movement from input file No 2 and stores them into the *Bus* object

- *get_timetable(stop_id, dep_time)*

This function stores the data, the sequence number of *Stop*, and departure time at that *Stop* into *StopQue* of the *Bus*

- *return_id()*.

This function returns the *id* number of the *Bus*, and useful to check the *id* of a *Bus*

- *del_bus_stop()*

This function deletes the first *Stop* from the *StopQue* of a *Bus* when the *Bus* departs that *Stop*, and thus updates the *StopQue* of that *Stop*

- *return_stop_id()*

This function returns *id* of the first *Stop* in *StopQue* of the *Bus*, i.e. the approaching *Stop* number at which the *Bus* is going to *Stop*

- *return_stop_time()*.

This function returns the departure time of the *Bus* at the coming *Stop*

- *add_pass(destination)*

This function adds one passenger from *PassQue* of a *Stop* to *PassList* of the *Bus*

- *del_pass()*.

When the *Bus* reaches a *Stop*, this function will be called. This function deletes all the passenger from *PassList* of the *Bus* whose destination is that *Stop*.

- *population()*

This function, when called returns the *population* of *PassList* of the *Bus*, i.e. the number of passengers occupied the *Bus*.

- *store_prev_data()*

This function stores the previous *Stop id* number, and the departure time of the *Bus*.

- *return_prev_stop()*.

This function returns the sequence number of a previous *Stop*.

- *return_prev_time()*

This function returns the departure time of the *Bus* at the previous *Stop*.

- *return_no_Stops()*

This function returns the number of *Stops* the *Bus* has to pass through. In other view, this function gives the number of *Stops* in *StopQue* of a *Bus*.

- *check_dir(d)*

This function compares the direction of *Bus* and the direction *d* passed to the function as an argument and returns YES if they are same, and NO if not.

2.5.4 BEGINNING THE SIMULATION

Once the *Stop* and *Bus* objects are created, and the input is given to the model, the model calculates the *system_time*, the time to start the simulation process. In this model, the system time is defined as the time 30 minutes

before the minimum departure time of first *Bus* of all *Stops* Expressing mathematically,

$$system_time = \text{Min} \{ \text{dep_time of } first_bus \text{ from } Stop[i], \forall i \} - 30 \text{ minutes}$$

Hence, at *system_time*, the model starts simulating the public transit system on a given route network. Thereupon, *system_time* will be incremented by 5 minutes. During each of this five minute interval, passengers will be generated at all *Stops*, which will be explained in detail in section 2.5.4. Each *Stop* and *Bus* will be scanned at every five minute interval and boarding and alighting of passengers will be carried out. The section 2.5.5 explains the same process.

Also, each *Stop* will be examined during each five minute interval to see whether an additional *Bus* can be scheduled from that *Stop* or not. If there are more than one *Stop* from which an additional *Bus* could be scheduled, then that *Stop* which has the maximum saving in waiting time will be chosen to provide the additional *Bus*. The evaluation of alternate strategies to find *best_stop* from which an additional *Bus* could be scheduled will be explained in section 2.5.6. At every increment of *system_time*, the locations of all *Buses* on the network will be displayed graphically. To display the *Buses* on the network the position of each *Bus* at *system_time* is to be calculated. The section 2.5.7 briefly explains the same. Accordingly the model will carry through the simulation process until the termination criterion is found, which will be explained in section 2.5.8.

2.5.5 GENERATION OF PASSENGERS

This section explains how the passengers are generated randomly at each *Stop* as per specific probability distributions and parameters obtained from input file No 1. This model can handle the passenger arrivals as per Exponential, Normal, and Gamma distributions. Each *Stop* can have different, or same probability distributions, and the parameters. In input file No 1, the desired probability distributions, and its parameters have to be specified for each *Stop*.

The function *generate_pass()* generates the passengers, assigns them a random destination, and stores them in *PassQue* of respective *Stop*. At each five minute increment to *system_time*, this function will be called for each *Stop* if there is at least one departing *Bus* from that *Stop* within 30 minutes from *system_time*. In other words, passengers will not be generated at any *Stop* if there is no *Bus* to depart that *Stop* within half an hour from *system_time*. This model assumes that passengers start arriving as per pre-decided probability distributions at any *Stop* thirty minutes prior to the departure time of *Bus* from that *Stop*. This implies that all passengers are aware of *Bus* timings from each *Stop*. Now let us have some idea on how the passengers are generated in this model as per different probability distributions at *Stops*. Though the flow charts will be used in later section to understand the logic in a better way.

a) EXPONENTIAL DISTRIBUTION :

The function *generate_pass()* generates the passengers at any *Stop* as per Exponential distribution if 'EX' is entered in input file No 1 as distribution at that *Stop*. Exponential distribution will have mean as its parameter. The parameter λ , the mean or inter-arrival rate should be greater than 0, in any

case If the value of λ entered is less than zero, this function takes a 2.0 as the default value of λ , and proceeds with the further calculations. In this function inverse-transform technique is used to generate Exponential random variates.

Let X have the exponential distribution with mean λ . The distribution function is -

$$F(x) = \begin{cases} 1 - e^{-x/\lambda} & \text{if } x \geq 0, \\ 0 & \text{otherwise} \end{cases}$$

So to find F^{-1} , we set $u = F(x)$, and solve for x to obtain

$$F^{-1}(u) = -\lambda \ln(1-u)$$

Thus to generate the desired random variate we first generate a $U \sim U(0,1)$, and then let $x = -\lambda \ln U$. It is possible in this case to use U instead of $1 - U$, since $1 - U$ and U have the same $U(0,1)$ distribution. This saves a subtraction (Law, and Kelton, 1991).

b) NORMAL DISTRIBUTION :

The function `generate_pass()` generates the passengers as per Normal distribution if NR is the desired distribution at any *Stop*. The two parameters of Normal distribution, i.e. mean μ and variance σ^2 have to be entered in the input file. This function however assumes the minimum values of mean and variance as 0 and 1 respectively.

The polar method is used in this function to generate $N(0,1)$ random variates (Law and Kelton, 1991). Which is as follows -

1. Generate U_1 , and U_2 as IID $U(0,1)$. Let $V_i = 2U_i - 1$ for $i = 1, 2$.

Let $W = V_1^2 + V_2^2$.

2. If $W > 1$, go back to step 1.

Otherwise, let $Y = \sqrt{(-2\ln W)/W}$. $X_i = V_i Y$, $i = 1, 2$.

Then X_i , $i = 1, 2$ are IID $N(0, 1)$ random variates.

Having $X \sim N(0, 1)$, we can obtain $X' \sim N(\mu, \sigma^2)$ by setting $X' = \mu + \sigma X$.

c) GAMMA DISTRIBUTION :

The function `generate_pass()` generates passengers as per Gamma random variates if the desired distribution at a *Stop* is entered as *GM*. The parameters of Gamma distribution are: shape parameter $\alpha > 0$, the scale parameter $\beta > 0$. The mean and variance of Gamma distribution are $\alpha\beta$, and $\alpha\beta^2$ respectively. This function takes 1, and 1 as the minimum values of α , and β . The algorithm, recommended by Cheng is used in this function to generate Gamma random variates, which generates $\text{gamma}(\alpha, 1)$ random variates (Law, and Kelton, 1991).

The prespecified constants are $a = 1 / \sqrt{(2\alpha - 1)}$, $b = \alpha - \ln$

4, $q = \alpha + 1/a$; $\theta = 4.5$; and $d = 1 + \ln \theta$.

1. Generate U_1 , and U_2 as IID $U(0, 1)$.
2. Let $V = a \ln[U_1 / (1 - U_2)]$, $Y = \alpha e^V$, $Z = U_1^2 U_2$, and $W = b + qV - Y$.
3. If $W + d - \theta Z \geq 0$, return $X = Y$. Otherwise, proceed to step 4.
4. If $W \geq \ln Z$, return $X = Y$. Otherwise, go to Step 1.

Given $X \sim \text{Gamma}(\alpha, 1)$ random variate one can obtain $X' \sim \text{Gamma}(\alpha, \beta)$ variate for any $\beta > 0$, from $X' = \beta X$.

ASSIGNING THE DESTINATIONS :

As stated earlier, the function `generate_pass()` generates the passengers as per pre-decided distributions, and assigns them a destination

randomly. The destinations will be assigned to passengers with the help of OD matrix entered in input file No. 5. Each element of OD matrix represents the daily demand from one *Stop* to the other. A function `OD_manipulation()` is used to manipulate the initial OD matrix so that each element of manipulated OD matrix represents the cumulative percent of trips (daily demand) from one *Stop* to the other.

In the function `generate_pass()` the manipulated OD matrix will be used. A random variate $U \sim U(0,1)$ will be generated and if that random number matches with any block of cumulative percent of trips of all destinations for a given *Stop*, that destination will be the passenger's destination. The flow chart will illustrated in section 3.3.4 to explain the same logic.

2.5.6 SCANNING STOPS AND BUSES

In this section let us see how this model scans each *Stop*, and each *Bus*, and how it alights/boards the passengers from/to each *Bus*. This process will be repeated for each *Stop*, and for each increment of *system_time*.

For each increment of *system_time*, following steps will be taken For i^{th} *Stop*,

1. Calling `return_id()` of `Stop[i]`, the *id.* of that *Stop* is stored in `Stop_no`.
2. The passengers waiting at `Stop[i]` is obtained by calling `Stop[i].population()`
3. From the *BusQue* of `Stop[i]` the departure time of *Bus* , and its *id.* are noted as *bus_time*, and *bus_no* respectively. This implies, the *Bus* whose *id.* is *bus_no* departs the `Stop[i]` at *bus_time*. Now the *system_time* is compared with *bus_time*.

4. The *system_time* equal to *bus_time* implies that that *Bus* is about to depart.
Now the boarding and alighting of passengers to and from the *Bus* at *Stop[i]* will be done.
5. The *system_time* greater than *bus_time* implies that that *Bus* has already departed the *Stop*. In this case also, the alighting and boarding of passengers from and to the *Bus* at *Stop[i]* will be carried out.
6. The *system_time* less than the *bus_time* implies that the *Bus* has not arrived the *Stop[i]*. In this case, nothing will be done as there is no *Bus* at *Stop[i]*. Now the same process from step-1 will be repeated for next *Stop*, i.e. $(i + 1)^{\text{st}}$ *Stop*.

BOARDING AND ALIGHTING OF PASSENGERS :

Alighting and boarding of passengers from and to a *Bus* will be done only when the system time is greater than or equal to *bus_time*. The following steps will be taken to achieve this :

1. Scan the passengers in the *PassLink* of the *Bus*.
If there are any passengers whose destination is equal to *Stop_no*, unload them from *PassLink* of the *Bus* by calling the member function *del_pass()* of that *Bus*.
2. Call the member function *population()* of the *Bus*, obtain the *population* in that *Bus*, i.e. the number of passengers occupied the *Bus*.
3. Compare the *population* in the *Bus* with *BUS_CAP*, the maximum capacity of the *Bus*. If the *population* is equal to *BUS_CAP*, then the remaining steps will not be executed, as the *Bus* can not accommodate any more passengers. In this case, the allow the *Bus* to depart the *Stop*.

4. If the *population* in the *Bus* is less than *BUS_CAP*, load the *Bus* with the passengers from *Stop[i]*. Check the arrival time of first passenger in the *PassQue*.
5. Scan the *population* at the *Stop*, i.e. the passengers waiting at the *Stop[i]* by calling the member function *population()* of *Stop[i]*.
6. If the *population* at *Stop[i]* is greater than zero, and if the passenger's arrival time is before the departure time of the *Bus*, load the passenger into the *Bus* by calling the member function *add_pass()* of that *Bus*. If the arrival time passenger is greater than *bus_time*, allow the *Bus* to depart, as the passengers in the *Stop* arrived after the departure time of the *Bus*. After loading the passenger to the *Bus*, delete that passenger from *PassQue* of *Stop[i]* by calling *del_pass()* of *Stop[i]*.
7. If the *population* at *Stop[i]* is equal to zero, i.e. if there are no passengers at the *Stop[i]*, allow the *Bus* to depart, as there are no passengers waiting at *Stop[i]*.

MOVING THE BUS FROM STOP :

If there are no passengers at the *Stop[i]*, or if there is no space in the *Bus* for passengers, or if the alighting and boarding of passengers is finished, then allow the *Bus* to depart the *Stop*. Call *move_first_bus()* of *Stop[i]*, which deletes that *Bus* from the *BusQue* of *Stop[i]*, and updates the *BusQue*.

Once the *Bus* is moved out of *Stop[i]*, then the same procedure will be repeated for next *Stop*, i.e. *Stop[i + 1]*. If this procedure is repeated for all *Stops*, then the next step to be under taken is finding the *best_stop* from which an additional *Bus* could be scheduled. This method is described in the following section.

2.5.7 FINDING THE BEST STRATEGY TO PROVIDE AN ADDITIONAL BUS

This section explains the evaluation criterion to find the best strategy to provide an extra *Bus* in to the route network. This evaluation will be carried out at each five minute interval of *system_time*. The function *find_best_stop()* will be called each time, which examines all the *Stops* to find the *best_stop* which can provide the maximum saving in waiting time for the passengers.

SELECTING THE ALTERNATIVES :

First the alternative *Stops* for *best_stop* will be traced out based on some heuristic conditions, then the *best_stop*, the best of all alternatives will be found, and an additional *Bus* will be suggested by the model. The three conditions that have to be satisfied for a *Stop* to be the one of alternative are -

- The basic condition is that the *Stop* must have at least one extra *Bus*. A *Stop* with out an extra *Bus* can not be considered as an alternative as it is not possible to schedule any *Bus* from that *Stop*.
- The condition favoring system operators is that there must be at least some minimum number of passengers waiting at a *Stop* which satisfies the first condition. This condition is imposed keeping in view the operators' benefits. If there are a few number of people waiting at the *Stop* will not make any good for the operators. Any number which suits the system can be considered as the minimum number of passengers. However, in this model, 20 is considered as the

minimum number. More clearly, only that *Stop* which has minimum 20 number of passengers waiting at *system_time* is said to be satisfy the second condition.

- The third condition is that there must be no *Bus* at a *Stop* with departure time lesser than or equal to *system_time* plus some minimum time period. If a *Stop* satisfies the first two conditions, and only if there is no *Bus* from that *Stop* to depart within some minimum period of time from *system_time*, that *Stop* can be considered as the alternative. This minimum time period can be any thing from 0 minute, however minimum time period considered in this model is 5 minute. So, a *Stop* to be one of the alternatives have to satisfy the first two conditions, and there must be no *Bus* leaving that *Stop* with departure time falling in the five minute period from *system_time* onwards.

If there are no *Stops* which satisfy all the three conditions, then there would be no alternatives, and no additional *Bus* will be suggested. If there is only one *Stop* satisfying all the three conditions, then no evaluation of alternatives is necessary, as there is only one alternative, and that *Stop* will be considered as the *best_stop*, and an additional *Bus* will be suggested from that *Stop*. Only if there are more than one *Stop* satisfying all the three conditions, then evaluation of alternatives will be made to find the *best_stop* as explained here.

EVALUATING THE BEST ALTERNATIVE :

Evaluation of alternatives will be made only if there are more than one *Stop* which is considered as an alternative, i.e. which satisfy all three conditions stated above. For each alternative, first the saving in waiting time will be calculated. Then the alternative which has the maximum saving in waiting time will

be considered as the *best_stop*. The following steps will be followed to calculate the saving in waiting time for each alternative, say for *Stop[i]* -

1. Get *bus_time*, the departure time of next *Bus* from *Stop[i]* by calling *return_first_time()* of *Stop[i]*. Calculate the *time_diff*, the difference between the *system_time*, and *bus_time*.
2. $time_diff = system_time - bus_time$.

This implies that if an additional *Bus* is scheduled from *Stop[i]*, it will save the waiting time of each passenger by *time_diff* minutes.

3. Now get the *population* of *Stop[i]* from *population()* of that *Stop*.
4. Saving in waiting time at *Stop[i]* is the product of *population* at *Stop[i]* and *time_diff*.
5. Similarly get the saving in waiting time at all the other *Stops* if the *Bus* from *Stop[i]* is scheduled at *system_time*. Saving in waiting time at each of the *Stops*, other than *Stop[i]* is computed as the product of *population* of that *Stop*, and *time_diff*.
6. Now calculate the total saving in waiting time which is the sum of saving in waiting time of all *Stops*.
7. In case of movement of *Buses* on both directions, calculate the total saving in waiting time at a *Stop* in both directions separately, and the direction in which total saving is maximum should be taken into account.

Once all the *Stops* are evaluated with respect to the total saving in waiting time, the *best_stop* will be that *Stop* with maximum total saving in waiting time. This model evaluate the *best_stop* considering the both directions of movement. Thus and so the function *find_best_stop()* finds the *best_stop*, and the

direction of *Bus* to be scheduled from that *Stop*. The model displays a message graphically which states that an additional *Bus* is scheduled from the *best_stop* at the *system_time*, and gives the user the choice to accept it or reject. If the user accepts the suggestion, then the new *Bus* will join the fleet on the network. In this case the *FLEET_SIZE* will be incremented by one, and the *free_bus* of the *best_stop* will be decremented by one, and the simulation continues further. If the user rejects the suggestion made by the model, then the new *Bus* will not be scheduled and the simulation continues further.

2.5.8 COMPUTING BUS LOCATIONS

This section explains how the at every increment of *system_time* the *Bus* positions are calculated to display their locations on the network. The function *get_bus_locations()* will be called after the function *find_best_stop()*. The following steps will be followed by the function *get_bus_locations()*.

At any *system_time*, for every *Bus* -

1. For a *Bus*, from *StopQue* get the next *Stop* number, and departure time at that *Stop* using functions *return_stop_id()*, and *return_stop_time()*.
2. Get the previous *Stop* details for a *Bus* from *return_prev_stop()*, and *return_prev_time()*.
3. The *system_time* equal to *prev_time* -1, or *prev_time* implies that the *Bus* is at *prev_stop* at *system_time*. Thus the position of that *Bus* is that of the *prev_stop*.
Now plot the position of *Bus* on the network. And go to step 1, repeat for next *Bus*.

4. The *system_time* equal to *next_time* implies that the *Bus* is at *next_stop* at *system_time*. So the position of the *Bus* is that of *next_stop*. Plot the position of the *Bus* on the network, and go to step 1 and repeat for next *Bus*.
5. The *system_time* greater than *prev_time*, and less than *next_time* implies that the *Bus* is in between the two *Stops*. In this case it is necessary to do some calculations to get the position of the *Bus*. Proceed to step 6.
6. Compute the *time_lag*, the difference of *prev_time*, and *system_time*. Compute the *tot_dist*, the distance between *next_stop*, and *prev_stop* in terms of pixels. Obtain the travel time from *prev_stop* to *next_stop* from input file No. 4.
7. Now calculate the desired speed of the *Bus*, which is equal to *tot_dist* divided by the travel time. Get *move_dist*, distance (in terms of pixels) to move the *Bus* from *prev_stop* is equal to the desired speed of the *Bus* multiplied by the *time_lag*.
8. Calculate the slope of *Bus* movement from *prev_stop* to *next_stop* depending on the direction of the *Bus*. Obtain the angle θ , which is inverse tangent of slope.
9. Now, at *system_time* the current position of the *Bus* on the network is obtained from -

$$Bus.x_{co} = prev_stop.x_{co} + move_dist \times \cos \theta'$$

$$Bus.y_{co} = prev_stop.y_{co} + move_dist \times \sin \theta'$$

$$\begin{aligned} \text{where } \theta' &= \theta && \text{if the slope is south east, or north west.} \\ &= 90 - \theta && \text{if the slope is south west, or north east} \end{aligned}$$

10. Plot the *Bus* position on the network. Go to step 1, and repeat for the next *Bus*, until all *Buses* are plotted.

2.5.9 *TERMINATION CRITERION*

The model will proceed with the simulation till the termination criterion is found. If the last *Bus* from a *Stop* has departed, then that *Stop* is said to be empty. So if all *Stops* are found empty then the termination criterion is supposed to be satisfied. To check whether a *Stop* is empty or not call the member function `return_no_Bus()`, which returns the number of *Buses* in *BusQue* of that *Stop*. If the termination criterion is found, the model displays a message graphically that all *Stops* are empty, and asks the user to quit the model as no further simulation is possible.

CHAPTER III

PROGRAM STRUCTURE

3.1 ABOUT TURBO C⁺⁺

As stated in section 2.2 this program is developed with OOP approach using C⁺⁺ and run on Turbo C⁺⁺ compiler Version 2.0 in an MS-DOS environment. Turbo C⁺⁺ provides a powerful environment called *integrated development environment* (IDE) for creating and executing a program. The IDE is completely menu-driven and allows the user to create, edit, compile, and run programs using what are known as *dialogue boxes*. Turbo C⁺⁺ requires MS-DOS 2.0 or higher, and runs on PC XTs, ATs, PC/2S, and compatibles. It needs at least 640 KB of memory, a hard disk, and a floppy disk drive. The hard disk should have some what more than 6 MB of free space. Turbo C⁺⁺ will also run in Microsoft Window DOS box. Turbo C⁺⁺ works with any 80 column monitor either character based (which usually means monochrome) or graphic-based (usually color). Turbo

C⁺⁺ can also accommodate a mouse, how ever it is not necessary; one can perform all operations from the key board.

3.2 **MAIN PROGRAM**

The main program is divided into 6 major functions, a few of which are further divided into sub functions. This section explains the complete program with the help of flow charts. The six functions which will be explained in later sections are -

1. *graphics_display()*
2. *create_stops()*
3. *create_buses()*
4. *assign_time_table()*
5. *od_manipulation()*
6. *do_operation()*

3.2.1 **GRAPHICS_DISPLAY()**

The main program of this model calls five functions stated above. First function to be called by the main program is *graphics_display()*. This function in itself calls *initgraph()*, a library function which must be executed before any other graphic-mode function used. This library function switches the computer's display system into appropriate graphics mode. This function requires the *graphics.h* header file. After initiating graphics, *graphics_display()* function calls other graphic functions used in the program to create windows, push-buttons, and text. The steps which will be executed in this function are given below.

1. *initgraph()*

2. `display_main_window()`
3. `display_time_window()`
4. `display_push_buttons()`
5. `display_text()`

3.2.2 ***CREATE_STOPS()***

This is the function that will be called after the *graphics_display()*. This function reads the first element *MAX_STOP* of input file No. 1, and creates the *MAX_STOP* number of *Stop* objects, and then stores the data from input file No. 1 by calling the member function *get_data()* of each *Stop*. This function calculates *MAX_BUS*, the maximum number of Buses that can be used in the system which is the sum of *tot_bus* of all *Stops*.

3.2.3 ***CREATE_BUSES()***

This function opens the input file No. 2 and first reads *BUS_CAP*, the maximum capacity of a Bus. Then it creates the *MAX_BUS* number of Bus objects. Then it reads the input file No. 2, and computes *FLEET_SIZE*, the number of buses being operated initially, which is the number of Buses defined in the input file No. 2. Then it calls *get_data()* of each Bus, and stores the data into the respective Bus object.

3.2.4 ***ASSIGN_TIMETABLE()***

Once the required number of *Stop* objects, and Bus objects are created, the next step is to assign the time table to each *Stop* object, and *Bus* object. This file opens the input file No. 3 and reads the time table for each *Stop* of the ring road network, and stores them in respective *BusQue* of *Stops*, and *StopQue* of Buses

by calling the *get_timetab()* function of each *Stop*, and each *Bus*. The flow chart below explains the same process.

3.2.5 *OD_MANIPULATION()*

This function opens the input file No. 4, and reads the OD matrix of size *MAX_STOP*. The each element of OD matrix in the input file represents the daily demand from one *Stop* to the other. This function manipulates the OD matrix using normalization technique in such a way that each element represent the cumulative percentage of daily demand from one *Stop* to the other. The manipulated OD matrix will be used to assign the destinations randomly to the passengers by the function *generate_pass()*.

3.2.6 *DO_OPERATION()*

The functions explained so far in the previous sections open and read the four input files, create the *Stop* and *Bus* objects, assign the time table to them, and manipulate the OD matrix. But, they do no simulation, and scheduling. The function *do_operation()* is the important and most critical function, and it does the simulation and scheduling part of the modeling. This function contains sub functions, a few of which contain another level of functions. The sub functions used in this function are -

1. *find_system_time()*
2. *generate_pass()*
3. *get_bus_locations()*
4. *find_best_stop()*

The function *do_operation()* will be explained with the help of flow charts in the following sections. Each of the sub functions will also be described.

This function *do_operation()* first calls the function *find_system_time()* to get *system_time*, the time to start the simulation process. The *system_time*, in this model is defined as the time 30 minutes before the minimum of first bus departure time from all *Stops*. Now let us try to study the functions used in *od_manipulation()*. They are *generate_pass()*, *find_best_stop()*, and *get_bus_locations()*.

A) *generate_pass(stop_no)*

This function takes *Stop_no*, the *id* number of a *Stop* at which passengers are to be generated, and generates the passengers as per pre-decided probability distribution for a period of five minutes starting from *system_time*, assigns the random destinations to the passengers, and stores them in *PassQue* of respective *Stop*. The description of this function is given in section 2.5.4, which gives a precise over view of the function. However in this section let us study the same with the help of flow chart. The figure 3.3 shows the flow chart of the function *generate_pass()*.

B) *find_best_stop()*

The function *find_best_stop()* will be called at each increment of system time by five minutes, which evaluates the best strategy to provide an additional Bus on to the ring road. This function is explained in section 2.5.6 in detail. In this section the flow chart is given to understand the same more clearly. The figure 3.4 shows the flow chart of the function *find_best_stop()*.

C) *get_bus_locations()*

This function at each increment of system time calculates the positions of Buses and plots the Buses on the ring road. The section 2.5.7 explains the function. The flow chart is presented in this section to enable the readers understand the logic used in this function

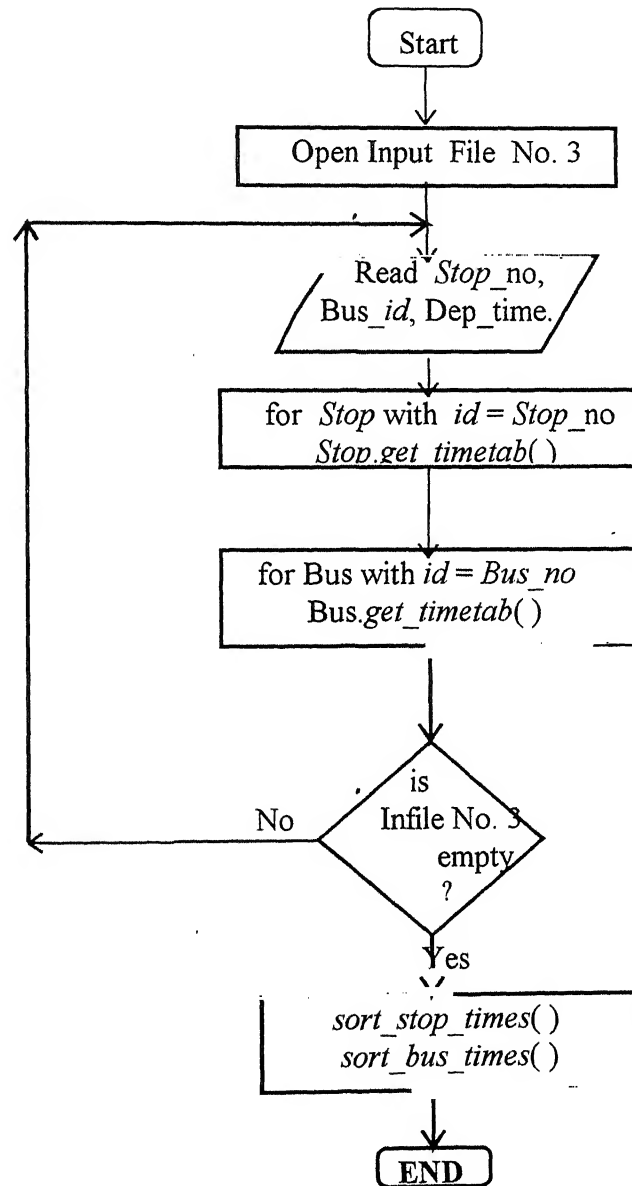
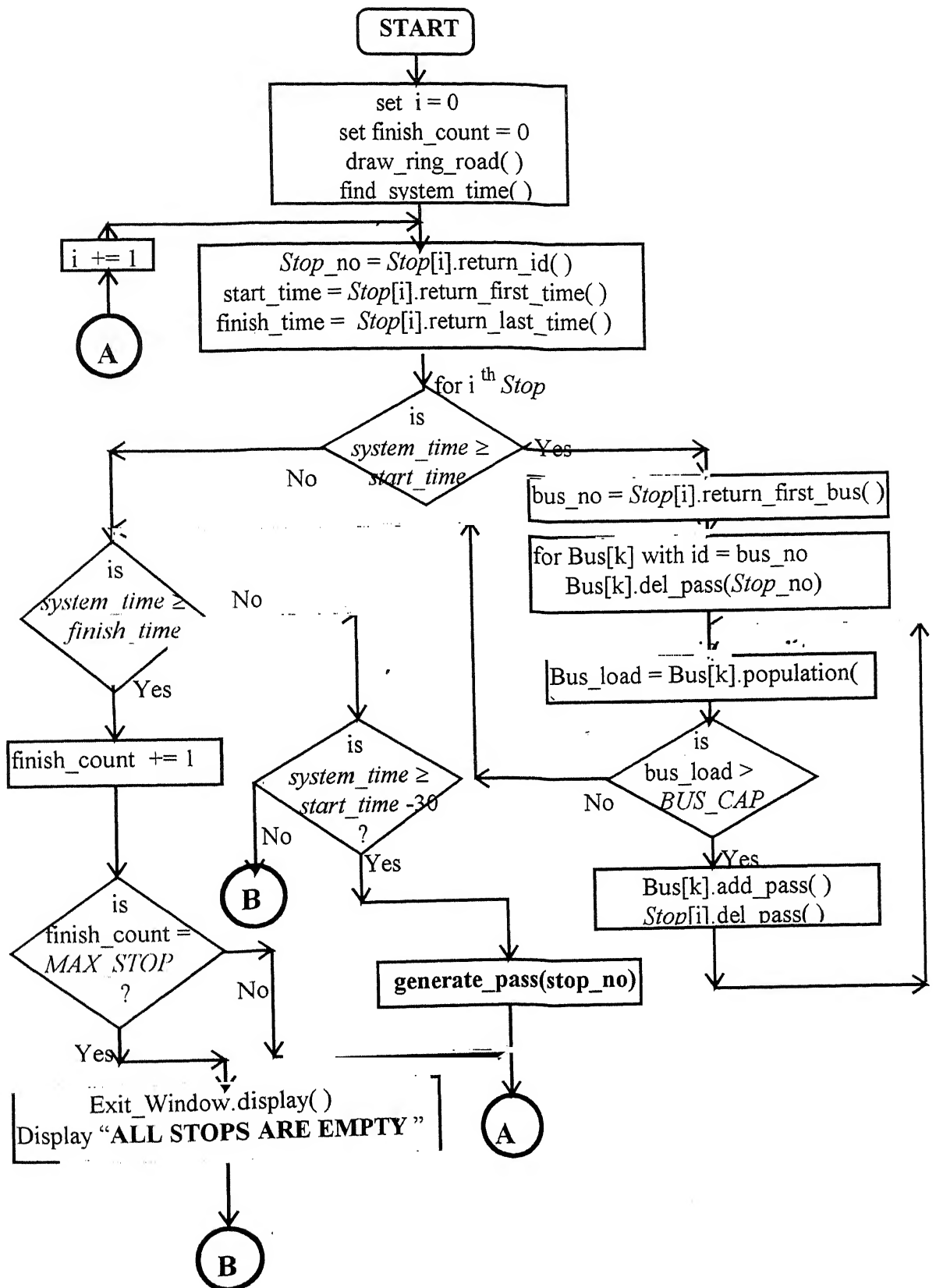


Fig. 3.1 Flow Chart for Function *assign_timetable()*

Fig. 3.2a Flow Chart for Function `do_operation()`

(...continued)

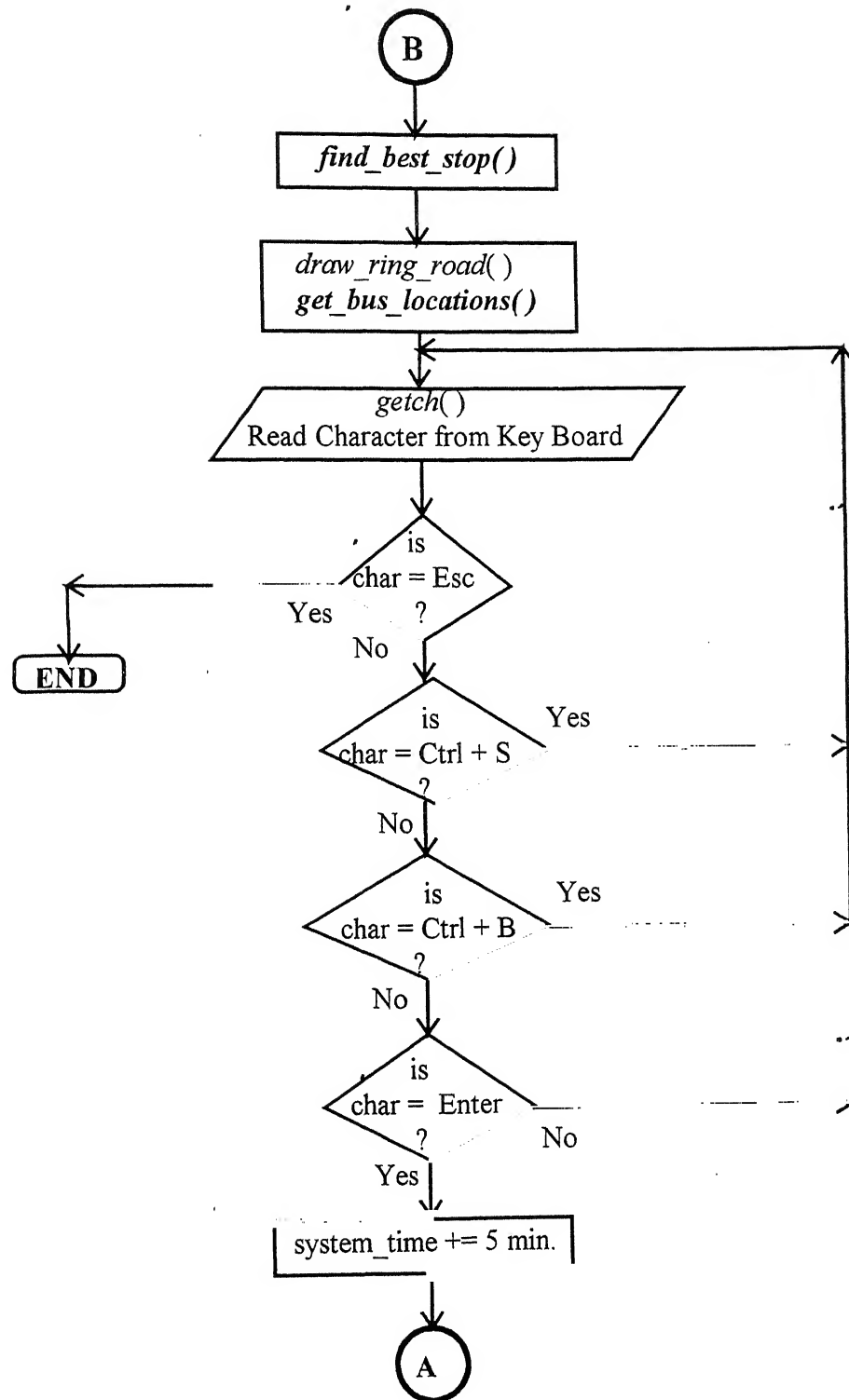
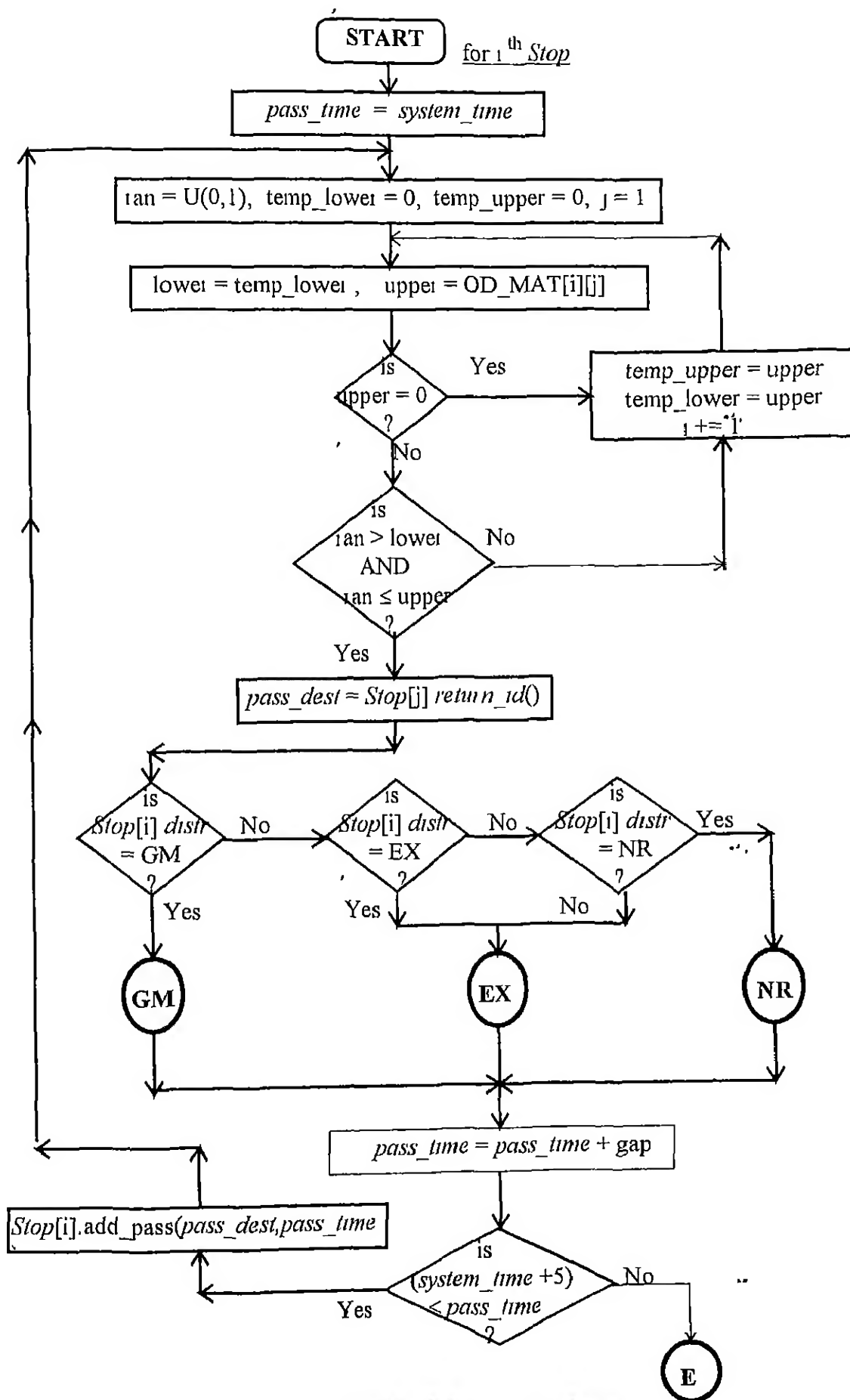


Fig. 3.2 Flow Chart for Function *do_operation()*



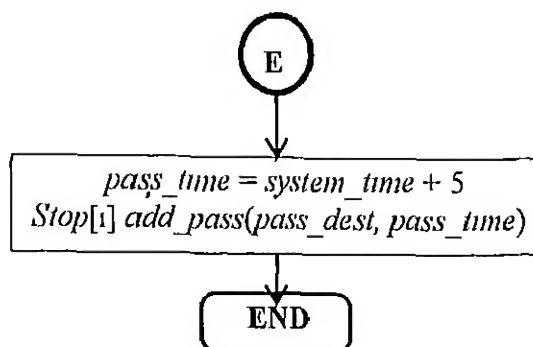


Fig. 3.3 Flow Chart for Function *generate_pass()*
 GM, EX, and NR in Fig 3.3 connects to the functions to generate Gamma (Fig 3.3a),
 Exponential (Fig 3.3b), and Normal (Fig 3.3c) random variates respectively

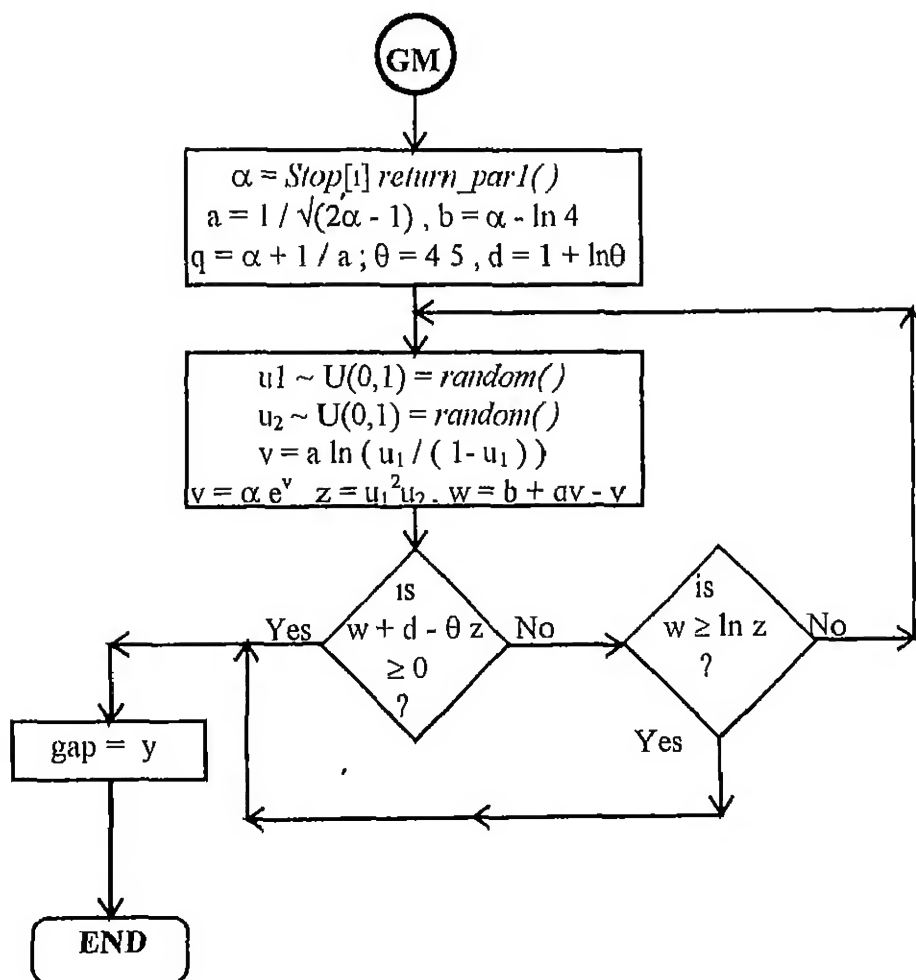


Fig 3.3a Function to generate Gamma random variates

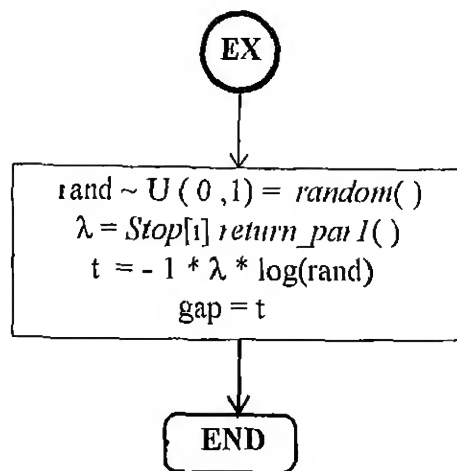


Fig. 3.3b Function to generate *Exponential* random variates

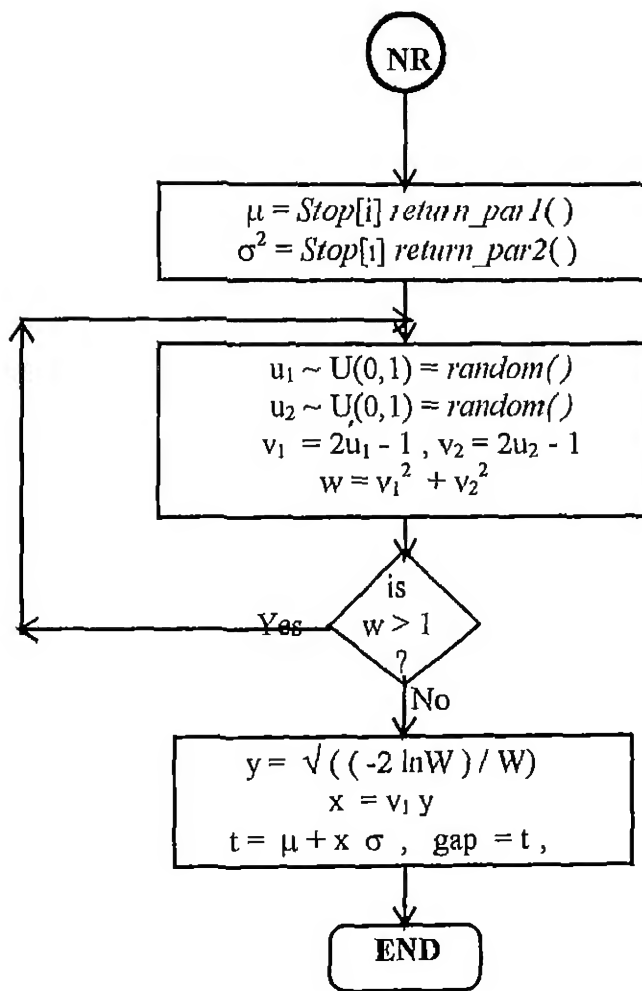
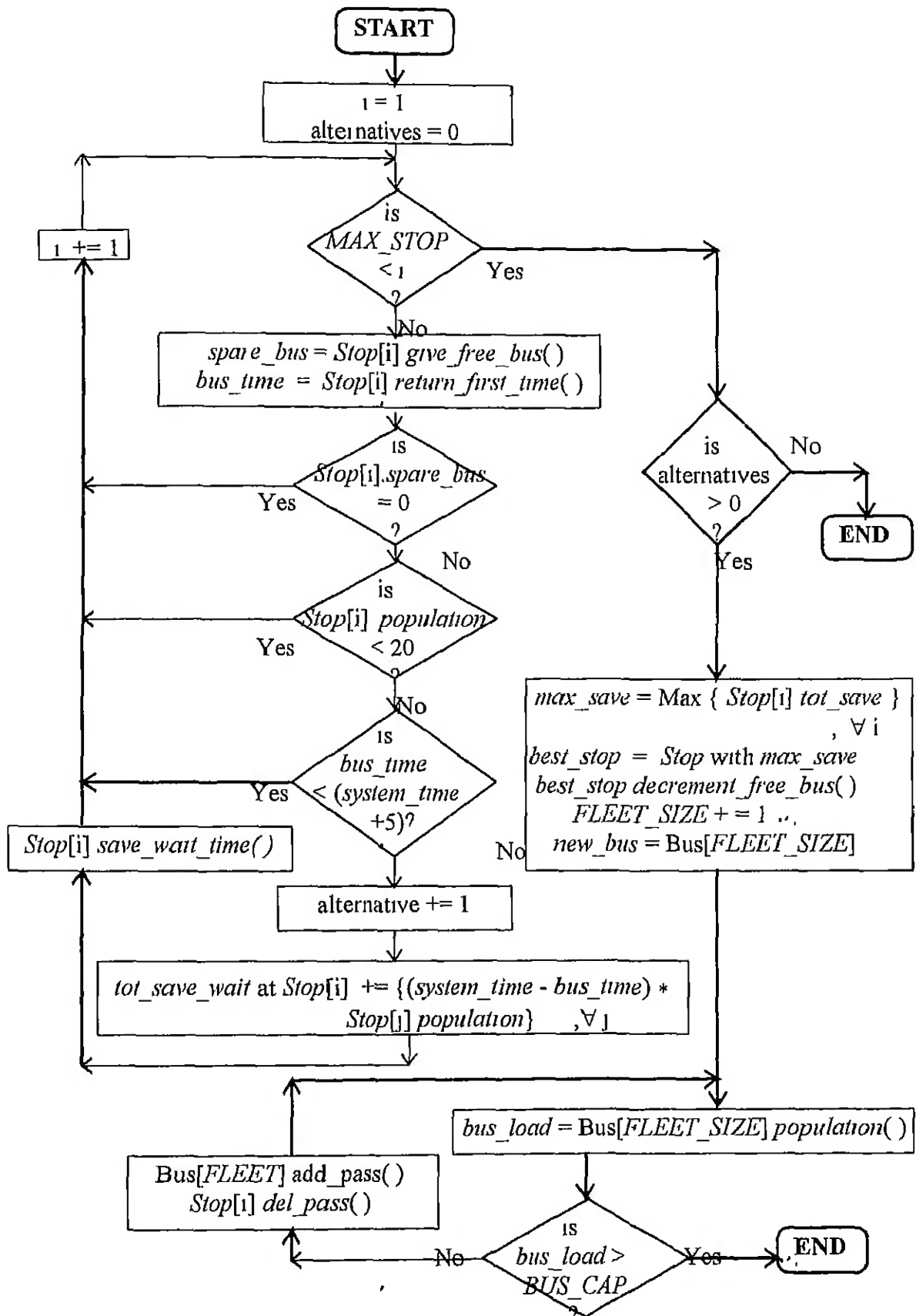


Fig. 3.3c Function to generate *Normal* random variates

fig 3.4 Flow Chart for Function `find_best_stop()`

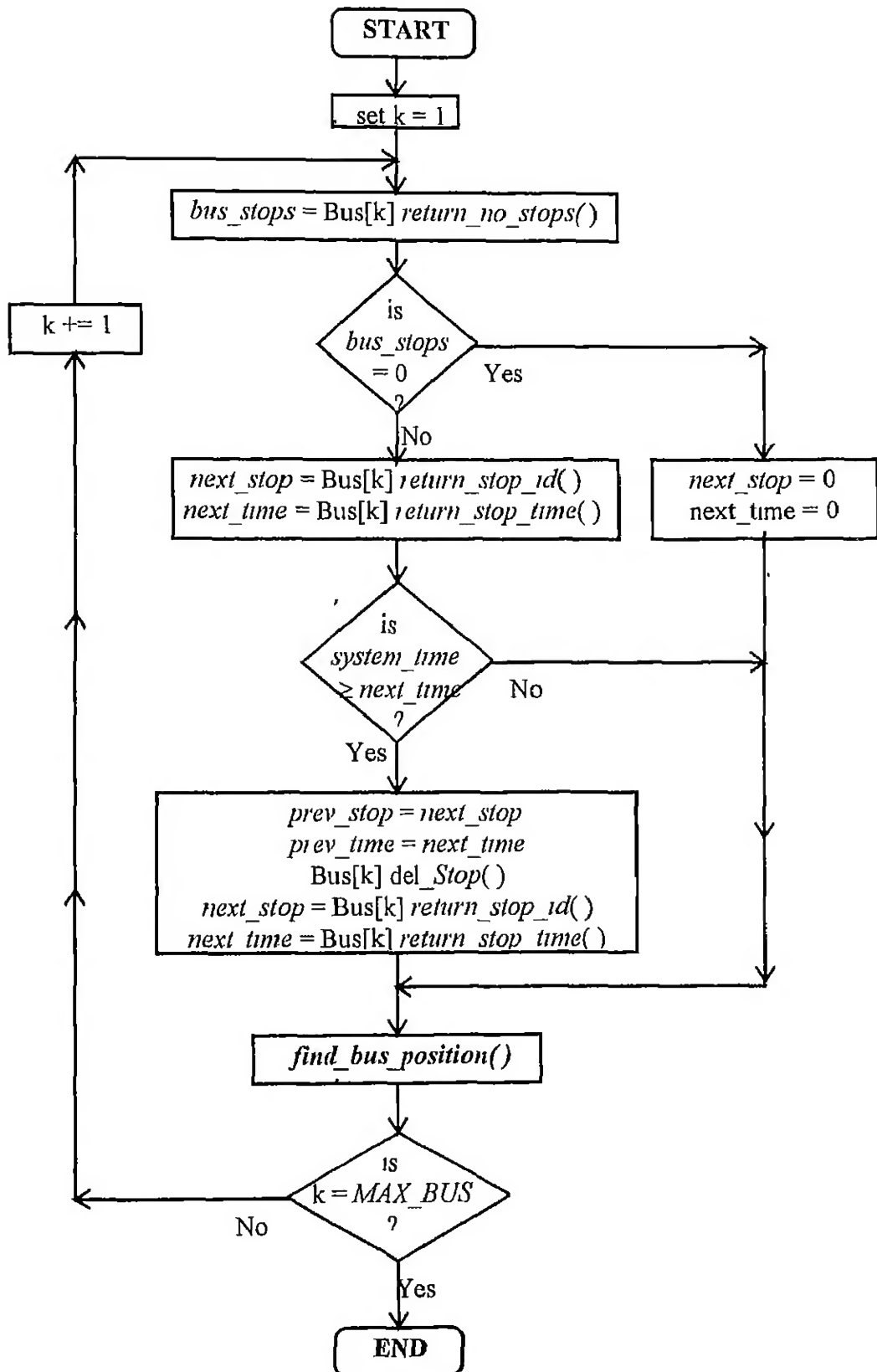
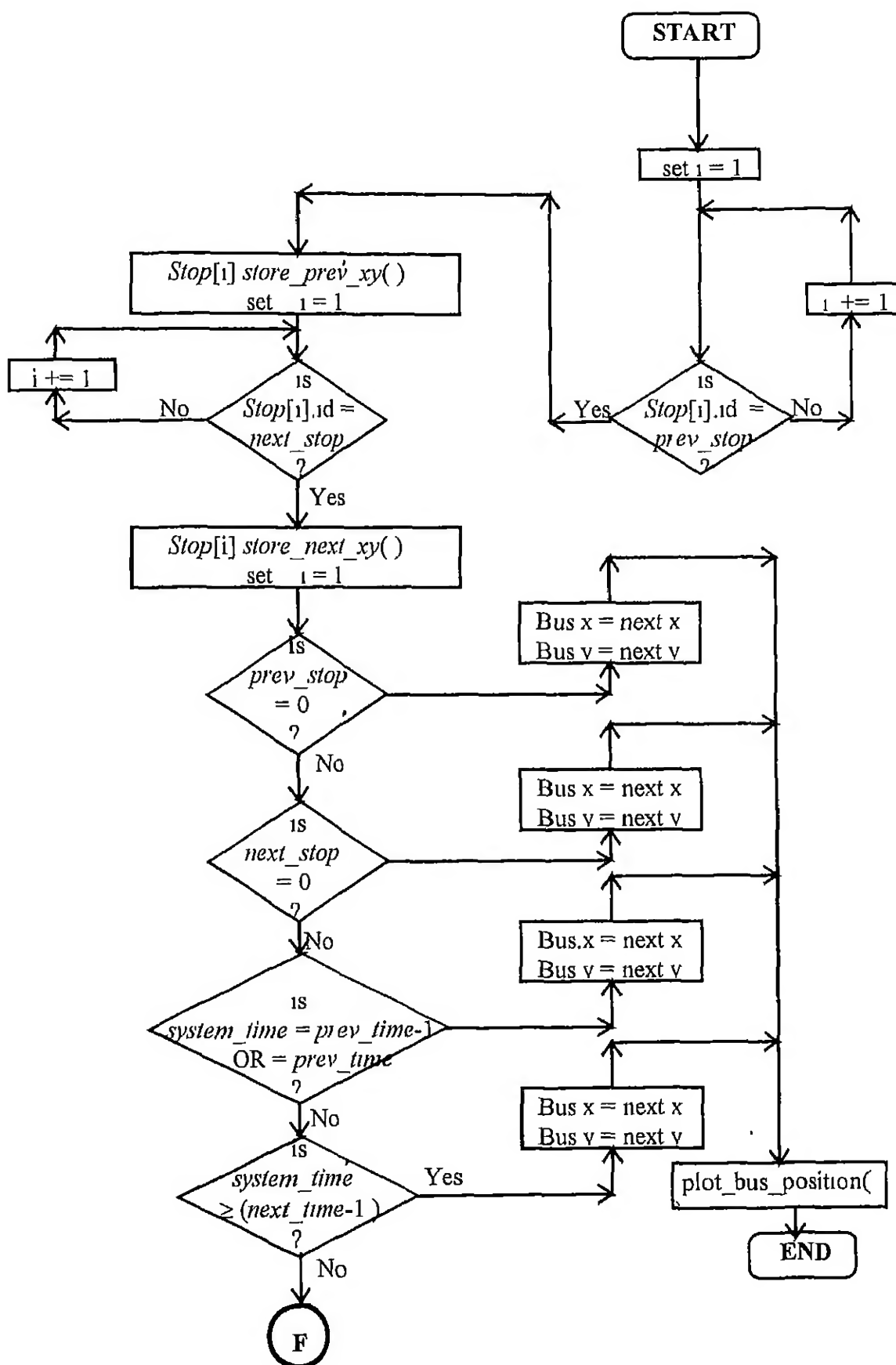


Fig. 3.5 Flow Chart for Function `get_bus_location()`



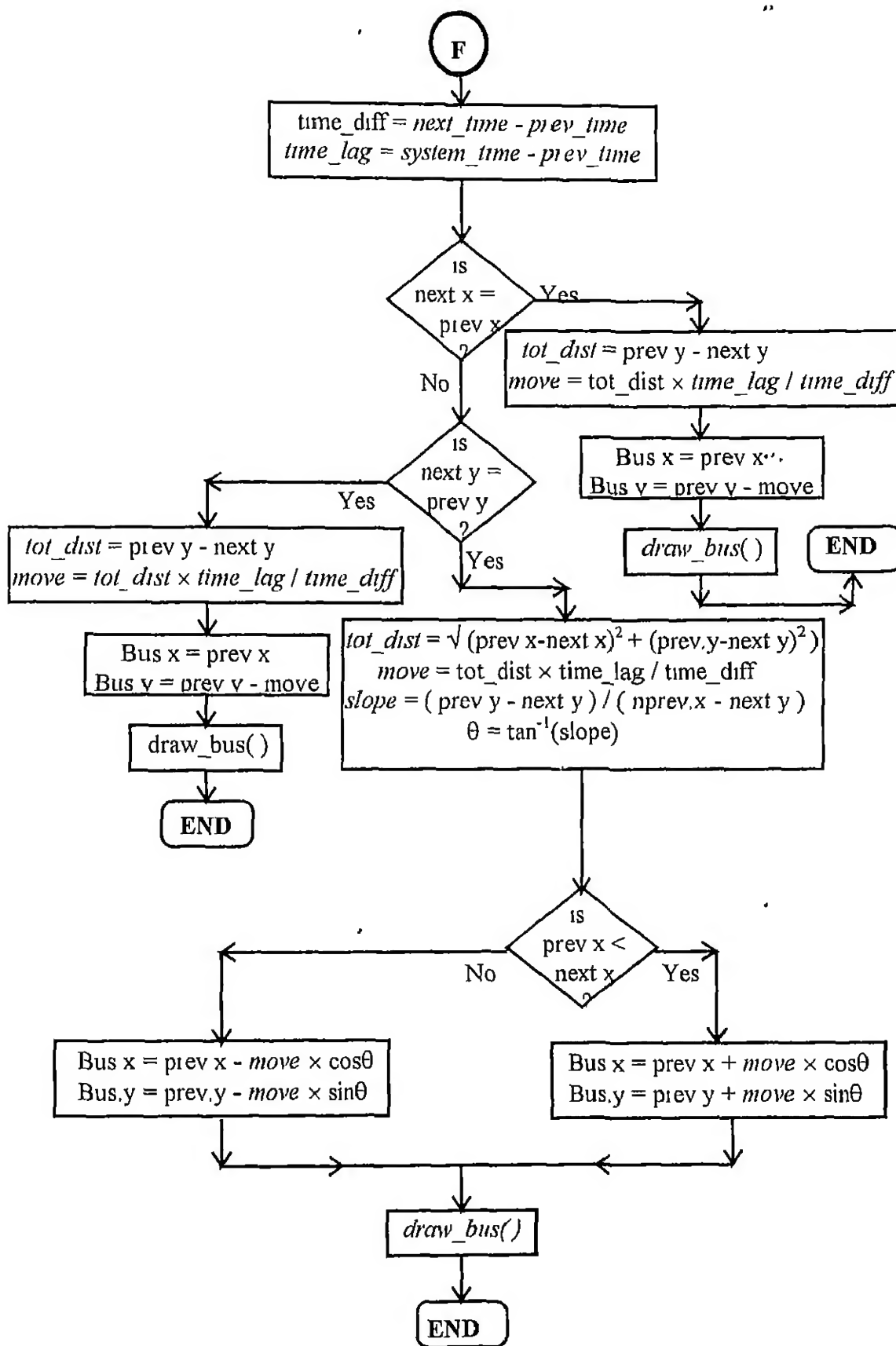


Fig. 3.6 Flow Chart for Function `find_bus_position()`

CHAPTER IV

MODEL APPLICATION

- A CASE STUDY

4.1 INTRODUCTION

The model discussed in the previous sections is tested for a case study of New Delhi metropolitan area. The ring road network of New Delhi city is considered and the transit system on the ring road is simulated using this model. The input for this model is extracted from the data collected from primary surveys, and secondary sources for the study 'Optimal Design of Urban Bus system' conducted by RITES for New Delhi metropolitan area (RITES, 1993). The data is available for the complete transportation network of New Delhi metropolitan area in terms of link distances, daily demand from one node to the other for all 1200 nodes. The input thus extracted is fed to the model and the output is obtained. The following sections explain the extraction of input and generation of output both in graphics part and non-graphics part.

4.2 INPUT TO THE MODEL

As explained before, the input to the model is extracted from the data collected for the study ' Optimal Design of Urban Bus System ' conducted for New Delhi metropolitan area (RITES, 1993). This section explains how the required input is derived from the complete data. First all the bus stops on the ring road network are identified, the daily demand matrix for those bus stops on the ring road is extracted from that of the complete transportation network, the major stops are identified as terminals on the ring road; the travel times on all the links of ring road network are obtained, and a tentative time table for the bus system on the ring road is generated.

4.2.1 IDENTIFICATION OF STOPS ON THE RING ROAD :

First the ring road is identified from the map of the complete network of Delhi area, and then all the Stops on the ring road are noted. For Delhi network with 1200 nodes the total number of nodes on the ring road are found to be 76. These 76 nodes are very closely spaced and it would be complicated to display the movement of buses graphically on the screen with such closely spaced nodes. Hence some closely spaced nodes are merged in to a single node, thus obtaining 31 nodes on the ring road network. These 31 nodes are identified based on the link distances, and the daily demand from one node to the other. The model is then used to simulate the public transit system on the ring road network of Delhi city with 31 bus stops on it. The x and y coordinates of all the 31 stops are obtained. The Table 4.1 gives the names of all 31 stops on the ring road network.

Table 4.1 The major Stops on the Ring Road Network of Delhi

Stop Sequence No.	Name of the Stop
1	RAJA GARDEN
2	PANJABI BAGH
3	ROTHAK ROAD
4	SHAKURPUR
5	WAZIRPUR
6	PITAMPURA
7	SHALIMAR BAGH
8	AZADPUR
9	MODEL TOWN
10	GURUTEJ BAGH NAGAR
11	KHALSA COLLEGE
12	KHYBER PASS
13	OLD SECRETERIATE
14	I S B T
15	YAMUNA BAZAR
16	RED FORT
17	I P STADIUM
18	PRAGATI MAIDAN
19	NIZAMUDDIN
20	KALEKHA
21	BHAGAWAN NAGAR
22	ASHRAM
23	LAJPAT NAGAR
24	MOOL CHAND
25	SOUTH EXTENSION
26	A I I M S
27	BHIKAJI
28	MOTI BAGH
29	DHAULA KUAN
30	BRAR SQUARE
31	MAYA PURI

The Table 4.2 gives the information of stops with respect to the desired probability distribution of passengers arrival at stops and its parameters. In this Table EX refers to Exponential distribution, NR refers to Normal Distribution, GM refers to Gamma distribution. In Table 4.2, par_1, and par_2 are respectively first and second parameters of the distribution. For Exponential distribution only par_1 is considered as β , and there will be no par_2. For Normal distribution par_1 is considered as μ , the mean, and par_2 is considered as σ^2 , the standard deviation. For

Gamma distribution par_1 is considered as α , the shape parameter, and par_2 is considered as β , the scale parameter.

Table 4.2 The Desired Probability Distributions of Passenger Arrivals at Stops

Stop Sequence No.	Desired Distribution	par_1 of the Distribution	par_2 of the Distribution
1	EX	2.5	
2	EX	3.2	
3	NR	2	0.5
4	EX	3	
5	GM	1.2	2
6	EX	3.6	
7	NR	3	0.5
8	EX	2.7	
9	EX	2.8	
10	EX	3.1	
11	NR	2.5	0.4
12	EX	3	
13	EX	3.5	
14	EX	2.9	
15	NR	4	1.33
16	EX	3.9	
17	EX	2.7	
18	GM	1.0	1.6
19	EX	3.1	
20	EX	2.3	
21	NR	2.4	.6
22	EX	2.9	
23	EX	2.87	
24	GM	2.1	1.3
25	EX	2.1	
26	EX	2.8	
27	NR	3	8
28	EX	2	
29	EX	2.95	
30	EX	3.8	
31	NR	2.7	.5

4.2.2 FORMATION OF OD-MATRIX :

From the

complete daily demand matrix of size 1200×1200 of Delhi area first the daily demand matrix for all 71 nodes on the ring road network is extracted. The OD matrix for the 31 stops is then obtained by merging the OD of smaller nodes (the nodes with less demand and closely spaced) with that of pre-identified stops. Thus obtained OD matrix of size 31×31 for all stops on the ring road network of Delhi area. Now each element of this matrix represents the daily demand from one stop to the other, only on the ring road network. The table 4.3 gives the total productions of all the Stops in terms of daily demand.

Table 4.3 Total Productions of all Stops

Stop Sequence No.	Total Productions of the Stop	Stop Sequence No.	Total Productions of the Stop
1	3560	16	716
2	4331	17	1593
3	1672	18	1645
4	2791	19	2141
5	1541	20	1129
6	1441	21	894
7	2580	22	487
8	3072	23	1045
9	2974	24	932
10	2613	25	1464
11	3573	26	837
12	3727	27	2260
13	3028	28	2781
14	383	29	1383
15	1339	30	1324
		31	1950

4.2.3 IDENTIFICATION OF TERMINALS :

After the stops on the ring road are identified, it is necessary to have few terminals which could supply buses to the ring road. A terminal in this model is defined a stop which supplies the buses to the route network under

consideration Each of the terminal will have some number of available buses, which is referred to as `tot_bus` in the model The stops which are not terminals will not have any buses, i.e. `tot_bus` for such stop will be zero. With the initial time table given to the model as input, some number of buses will be scheduled from the each terminal Considering the remaining buses at each terminal, the model finds the best terminal from which the additional bus could be scheduled

Six terminals are identified out of 31 stops on the ring road based on the total demand from each stop to all the other stops It is assumed in this model that these terminals supply buses to the ring road network, i.e. all the buses originate from any of the terminals, move on the ring road serving all the intermediate stops and they finally stop at the respective terminals according to the pre-determined timetable. The Table 4.4 gives the names of the selected terminals on the ring road, and the number of buses available at these terminals

Table 4.4 The Terminals on the Ring Road Network of Delhi.

Terminal No.	Name of the Terminal	No. of Buses at Terminal
1	RAJA GARDEN	8
8	AZADPUR	8
14	I.S.B.T	8
18	PRAGATI MAIDAN	8
23	LAJPAT NAGAR	8
29	DHAULA KUAN	8

4.2.4 BUS INFORMATION :

The simulation is initially started with 24 buses, four buses from each of the six terminals. Thus the `FLEET_SIZE` is equal to 24 before starting the simulation The maximum value of the `FLEET_SIZE` is `MAX_BUS`, the total number of buses in the system, which is equal to the 43 in this case study. This model suggests a few more additional buses which will be added to the `FLEET_SIZE`. The

headway of these buses is kept as 20 minutes at each terminal. The movement of buses on both directions (Clock Wise, and Anti Clock Wise) on the ring road is considered. The Table 4.5 gives the information of buses initially under operation is given in terms of its starting terminal, starting time, and its direction of movement.

Table 4.5 Information of Buses
(CW - Clock Wise, ACW - Anti Clock Wise)

Bus Sequence No.	Starting Terminal	Starting Time (Hrs.)	Direction of Movement
1	1	610	CW
2	1	630	ACW
3	1	650	CW
4	1	710	ACW
5	8	605	CW
6	8	625	ACW
7	8	645	CW
8	8	705	ACW
9	14	605	CW
10	14	625	ACW
11	14	645	CW
12	14	705	ACW
13	18	600	CW
14	18	620	ACW
15	18	640	CW
16	18	700	ACW
17	23	615	CW
18	23	635	ACW
19	23	655	CW
20	23	715	ACW
21	29	600	CW
22	29	620	ACW
23	29	640	CW
24	29	700	ACW

4.2.5 PREPARING INITIAL TIMETABLE :

An initial timetable is prepared to test the model. First the travel distance on each link is obtained from the data. For this case, ring road with 31 stops on it, the total number of links are 62, considering the movement of buses in both directions i.e. clockwise, and anti clockwise. Assuming a constant speed of 15

kmph the travel time on each link are calculated in terms of minutes. Having given in the input the starting terminal and direction of movement of each of the 24 buses as shown in Table 4.5, the tentative timetable is prepared. The timetable prepared to test this model covers the morning peak period from 0700 to 1000 hrs. Considering the direction of movement of bus on ring road, and its starting terminal the next destination of that bus is obtained, and the departure time of the bus is computed using the following equation-

For a bus,

$$\text{departure time at stop}[i] = \text{departure time at stop}[i-1] + \text{travel time}(i-1, i) + \text{boarding/alighting time of passengers at stop}[i].$$

To develop initial timetable it is necessary to have the information of each link on the ring road network, in terms of travel distance, and travel time. Table 4.6 gives the details of each link on the ring road of Delhi city.

Table 4.6 Travel Distances, and Travel Times on Links of Ring Road.

From - Stop No.	To - Stop No.	Link Distance (meters)	Travel time (minutes)	Link Direction CW - Clock Wise ACW - Anti Clock Wise
1	2	2400	9	CW
2	1	2400	9	ACW
2	3	700	2	CW
3	2	700	2	ACW
3	4	1270	5	CW
4	3	1270	5	ACW
4	5	1380	5	CW
5	4	1380	5	ACW
5	6	780	3	CW
6	5	780	3	ACW
6	7	1050	4	CW

Table 4.6 cont'd

From - Stop No.	To - Stop No.	Link Distance (meters)	Travel time (minutes)	Link Direction CW - Clock Wise ACW - Anti Clock Wise
7	6	1050	4	ACW
7	8	860	3	CW
8	7	860	3	ACW
8	9	2230	8	CW
9	8	2230	8	ACW
9	10	1380	5	CW
10	9	1380	5	ACW
10	11	680	2	CW
11	10	680	2	ACW
11	12	1100	4	CW
12	11	1100	4	ACW
12	13	1150	4	CW
13	12	1150	4	ACW
13	14	1760	7	CW
14	13	1760	7	ACW
14	15	1230	4	CW
15	14	1230	4	ACW
15	16	880	3	CW
16	15	880	3	ACW
16	17	2000	8	CW
17	16	2000	8	ACW
17	18	1680	6	CW
18	17	1680	6	ACW
18	19	2880	11	CW
19	18	2880	11	ACW
19	20	1600	6	CW
20	19	1600	6	ACW
20	21	600	2	CW
21	20	600	2	ACW
21	22	1250	5	CW
22	21	1250	5	ACW
22	23	1600	6	CW
23	22	1600	6	ACW
23	24	1200	4	CW
24	23	1200	4	ACW
24	25	1620	6	CW
25	24	1620	6	ACW
25	26	970	3	CW
26	25	970	3	ACW
26	27	1870	7	CW
27	26	1870	7	ACW
27	28	1710	6	CW
28	27	1710	6	ACW

Table 4.6 cont'd.

From - Stop No.	To - Stop No.	Link Distance (meters)	Travel time (minutes)	Link Direction CW - Clock Wise ACW - Anti Clock Wise
28	29	2250	9	CW
29	28	2250	9	ACW
29	30	1590	6	CW
30	29	1590	6	ACW
30	31	3450	13	CW
31	30	3450	13	ACW
31	1	1510	6	CW
1	31	1510	6	ACW

4.2.6 STORING THE RELEVANT DATA IN INPUT FILES :

After preparing the input data it is required to store them in appropriate input files. As mentioned in section 2.4 the input data must be stored in five input files. For this case study the input files contain the following data -

1. Input file No. 1, 'STOP_XY.IN' contains the x and y coordinates, the desired *distribution and its parameters*, and the total number of buses available for each of the 31 stops on the ring road. The first element of this file is 31, the number of stops under consideration. The maximum number of buses available in the system is equal to the sum of total number of buses of all stops. This is taken as 48 in this case study (Refer Table 4.4)
2. The input file No. 2, 'BUS_INFO.IN' contains the starting terminal and direction of movement of each bus. The first element of this file is 50, which is the capacity of the bus taken in this model. In this file the information of 24 buses is stored, i.e. the number of buses being operated on the ring road network before starting the simulation is 24. Thus the fleet size initially is equal to 24. The maximum value of the fleet size is the maximum number of buses in the system, i.e. 48.
3. The input file No. 3, 'TIME_TAB.IN' contains the initial timetable of the public transit system developed for this model. The format of this file is first stop

number, then the number of departing bus, and its departure time. The timetable generated as discussed in previous section is stored in this file. For this case study, this file contains initial timetable for all the 24 buses serving the 31 stops on the ring road network.

- 4 The input file No. 4, 'LINKTIME.IN' contains the travel time on each link of the ring road network. First the origin stop, then the destination stop, the travel time in minutes, and then the direction of that link is the format that is used in this file. For this case study the travel times of all 62 links of the ring road are stored in this file.
- 5 The input file No. 5, 'OD_MAT.IN' contains the daily demand matrix for all stops on the ring road network. This matrix for this case study is 31×31 symmetric matrix.

4.3 SIMULATION RUNS

The simulation process can be started by executing the program, i.e. by typing 'sim3000' at DOS prompt. The main window will be displayed which will have four push buttons. *Esc* button - to stop the simulation and to exit to DOS; *Enter* button - to continue the simulation; *Ctrl+S* button - to display the information of all stops at any instant of time, and *Ctrl+B* button - to display the information of all buses at any instant of time. The graphic display of this model is user interactive, and hence user can press any of the four buttons of his interest. There will be a Time window which displays the time of simulation. The idea of how the model works is already discussed in the previous chapters.

Figure 4.1 shows display of Main window of this simulation model. The four push buttons *Esc* key, *Enter* key, *Ctrl+S* key, and *Ctrl+B* key can be clearly seen in the figure, which on activating performs different actions. The Time

window in the main screen displays the time 0535 Hrs. just before starting the simulation. The Ring Road network of Delhi with 31 major stops on it can be observed. All the vehicles, represented by green color icons are at their respective terminals as the simulation has just started, and their departure time has not yet reached.

Figure 4.2 shows the window which will be displayed when the model suggests an additional bus to be scheduled. The two buttons to accept the additional bus, and to reject the additional bus can be activated by *Space bar* key, and *Esc* key respectively.

Figure 4.3 shows the Stop window, which will be displayed when the *Ctrl+S* key in the Main window is activated. This window provides the sufficient information of all stops such as the number of passengers waiting at a stop, the average and total waiting time of passengers, the sequence number and departure time of next bus, ... etc.

Figure 4.4 shows the Bus window, which will be displayed when the *Ctrl+B* key in the Main window is activated. This window displays the information of all buses such as the number of passengers occupied the bus, the direction of movement of bus on the ring road, the sequence number of, and departure time at previous stop, and next stop.

4.4 RESULTS AND DISCUSSION

The simulation for the case study of Delhi ring road network is carried over as discussed in section 4.3. The simulation process is started at 0600 hrs and terminated at 1130 hrs, thus covering the morning peak period 0700 hrs to 1000 hrs, and the results obtained will be discussed in the following sections.

4.4.1 ADDITIONAL BUSES :

As stated in section 4.2.4, there are 24 buses in the system that are being operated initially. This model has simulated the public transit system on the ring road of Delhi city for the morning peak period and has suggested the 19 additional buses to ply on the ring road. The details of the additional buses scheduled on the ring road is given in the following table. These additional buses originate at their respective starting terminal, move along the ring road serving all the stops on the ring road, and finally terminate at the then origin stop, i.e. starting terminal. The Table 4.6 gives the starting terminal, starting time, and the direction of movement of 19 additional buses.

Table 4.7 The Additional Buses Suggested by the Model

New Bus No.	Starting Terminal No.	Starting Time (Hrs.)	Direction of movement
25	29	610	CW
26	18	615	CW
27	14	620	CW
28	8	635	ACW
29	1	645	ACW
30	23	650	CW
31	14	705	ACW
32	18	720	CW
33	29	725	CW
34	8	730	ACW
35	23	745	ACW
36	1	750	ACW
37	8	810	CW

Table 4.7 Cont'd

New Bus No.	Starting Terminal No.	Starting Time Hrs.	Direction of movement
38	29	815	ACW
39	18	820	ACW
40	14	840	CW
41	18	845	CW
42	23	850	ACW
43	1	855	CW

4.4.2 SAVING IN WAIT TIME

In this section the save in the total waiting time of each stop is presented. The model has suggested 19 new buses in addition to the 24 initial buses. The additional buses are suggested based on the saving in total wait time, evaluating the best strategy as explained in section 2.5.5. Thus the scheduling of these 19 additional buses on the ring road has proved that the total waiting time at each stop is reduced. It has been found that the total waiting time at a stop when all the additional buses, suggested by the model are accepted is less than the total waiting time at that stop when no additional bus is accepted. This is presented in Table 4.7.

Table 4.8 Total Saving in Passenger Wait Times

Stop No.	Total Wait Time Rejecting New Buses (Minutes)	Total Wait Time Accepting New Buses (Minutes)	Saving in Total Wait Time (Minutes)
1	2752	1932	820
2	2491	2281	210
3	3043	2530	513
4	3287	2382	905
5	2566	2369	197
6	3573	3109	464
7	3642	2963	679
8	2798	2141	657
9	2649	2544	105

Table 4.8 Cont'd

Stop No.	Total Wait Time Rejecting New Buses (Minutes)	Total Wait Time Accepting New Buses (Minutes)	Saving in Total Wait Time (Minutes)
10	2702	2180	522
11	3902	3377	525
12	2894	2397	497
13	3343	2976	367
14	3758	3294	464
15	2992	2472	520
16	3632	3157	475
17	3425	3051	374
18	4535	3929	606
19	2857	2317	540
20	3168	2496	672
21	2654	2183	471
22	2938	2585	353
23	2379	1902	477
24	3057	2461	596
25	2468	1836	632
26	3648	3172	476
27	3746	3282	464
28	4316	3442	874
29	5674	4261	1413
30	3258	2843	415
31	3494	2657	837

4.4.3 NEW TIMETABLE

The model has suggested 19 additional buses, and all these 19 additional buses were accepted to ply on the ring road. The saving in total wait time due to the scheduling of additional buses is discussed in the previous section. The model has prepared the new timetable which includes the tentative timetable with 24 initial buses, and the timing of the 19 additional buses. The buses with sequence numbers from 1 to 24 are the buses in the initial fleet, and with sequence numbers from 25 to 43 are the newly scheduled buses. The revised timetable is presented in Appendix.

CHAPTER V

CONCLUSIONS

5.1 CONCLUSIONS

This model has the capability for dynamic scheduling of vehicles on a major corridor of a metropolitan city. This model simulates the public transit system on any route network, and suggests the optimal utilization of vehicles which minimizes the passenger waiting times at all stops. Considering the large variations in passenger demand it is necessary to have a transit system with dynamic scheduling of vehicles for optimal design. This model is flexible in terms of probability distributions of passenger arrival at stops. Passenger can arrive the stops as per any one of Exponential, Normal, and Gamma distributions, and the parameter of these distributions are as per user choice.

The model is developed with Object Oriented Programming (OOP) approach using C⁺⁺. The model supports the user interactive graphics, so that the user can obtain the information of all stops and buses at any instant of time and/or quit the simulation at any instant of time. The locations of all buses on the route network can be displayed at every 5 minute interval of time by the concurrent mode of animation. The software is developed and run on Turbo C⁺⁺ platform in an MS-DOS environment. The size of the problem will be greatly influenced by the computational capabilities, and the available memory.

This model is tested with a case study of Delhi city. The ring road network of Delhi metropolitan area is considered, and the public transit on the ring road is simulated. The data collected for a study 'Optimal Design of Urban Bus System for Delhi' is used partly as the input for this model. A tentative timetable is prepared, which is fed to the model. The model has revised the timetable, which includes the scheduling of additional buses suggested by the model. For the case study, the model has suggested 19 new buses in addition to the 24 initial buses. The saving in wait time at all stops due to the schedule of these additional buses is also presented.

5.2 LIMITATIONS

This model has some limitations which can be overcome by minor adjustments, and modifications to the software. The following limitations are thought of

-

- The model can simulate the transit operations on a major corridor of city but not many corridors.
- The model can not take care of overlapping routes
- The arrival rate of passengers at a stop is assumed to be constant in this model. Whereas most of the passengers arrive the stops based on the scheduled bus timings.
- The model has not considered the stochastic nature of bus arrivals.
- This model can display the locations of buses on the route network at every five minute interval, but not at any intermediate time.

5.3 SCOPE FOR FUTURE WORK

Considering the limitations mentioned in the above section, there is a lot of scope for the future work on this area

- The model could be developed so as to make on-line decisions of optimal bus scheduling for a city route network.
- The simulation for dynamic scheduling is limited to a single corridor in this model, which can be extended to many corridors with overlapping routes.

APPENDIX

Timetable revised by the model.

Includes the schedules of additional buses.

1 Stop No.	2 Bus No.	3 Departure Time (Hrs)	1 Stop No.	2 Bus No.	3 Departure Time (Hrs)	1 Stop No.	2 Bus No.	3 Departure Time (Hrs)
1	1	610	1	5	826	2	28	657
1	21	625	1	18	827	2	3	659
1	2	630	1	11	836	2	23	714
1	25	635	1	22	847	2	10	717
1	29	645	1	32	850	2	17	724
1	3	650	1	43	855	2	8	727
1	6	656	1	1	902	2	14	733
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26	25	840	27	21	837	28	7	832
26	34	848	27	34	841	28	34	835
26	12	853	27	12	846	28	12	840
26	31	853	27	31	846	28	31	840

1	2	3	1	2	3	1	2	3
28	21	843	29	34	826	30	14	801
28	25	853	29	12	831	30	5	807
28	16	856	29	31	831	30	36	809
28	18	901	29	1	837	30	11	817
28	3	908	29	7	841	30	34	820
28	23	923	29	16	847	30	12	825
28	20	941	29	18	852	30	31	825
28	41	941	29	21	852	30	32	831
28	37	957	29	25	902	30	16	841
28	40	957	29	22	912	30	1	843
28	33	1008	29	3	917	30	18	846
28	35	1011	29	20	932	30	7	847
28	39	1016	29	23	932	30	22	906
28	43	1113	29	41	950	30	3	923
28	42	1116	29	24	952	30	20	926
29	21	600	29	35	1002	30	24	946
29	25	610	29	37	1006	30	35	956
29	22	620	29	40	1006	30	41	956
29	23	640	29	39	1007	30	39	1001
29	17	650	29	33	1017	30	37	1012
29	2	655	29	38	1107	30	40	1012
29	24	700	29	42	1107	30	38	1101
29	13	705	29	43	1122	30	42	1101
29	29	710	30	21	606	30	43	1128
29	26	720	30	25	616	31	21	619
29	6	721	30	23	646	31	25	629
29	30	725	30	2	649	31	2	636
29	33	725	30	17	656	31	29	651
29	19	730	30	29	704	31	23	659
29	9	731	30	13	711	31	6	702
29	28	731	30	6	715	31	17	709
29	4	735	30	28	725	31	28	712
29	15	745	30	26	726	31	4	716
29	27	746	30	4	729	31	13	724
29	10	751	30	30	731	31	10	732
29	5	801	30	33	731	31	26	739
29	8	801	30	19	736	31	8	742
29	14	807	30	9	737	31	30	744
29	11	811	30	10	745	31	33	744
29	36	815	30	15	751	31	14	748
29	38	815	30	27	752	31	19	749
29	32	825	30	8	755	31	9	750

1	2	3
31	36	756
31	15	804
31	27	805
31	34	807
31	12	812
31	31	812
31	5	820
31	16	828
31	11	830
31	18	833
31	32	844
31	22	853
31	1	856
31	7	900
31	20	913
31	24	933
31	3	936
31	35	943
31	39	948
31	41	1009
31	37	1025
31	40	1025
31	38	1048
31	42	1048
31	43	1141

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